# Decarbonizing Development

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## Three Steps to a Zero-Carbon Future

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# Climate Change and Development

The Climate Change and Development Series was created in 2015 to showcase economic and scientific research that explores the interactions between climate change, climate policies, and development. The series aims to promote debate and broaden understanding of current and emerging questions about the climate-development nexus through evidence-based analysis.

The series is sponsored by the Climate Change Vice Presidency of the World Bank, and its publications represent the highest quality of research and output in the institution on these issues. The group is committed to sharing relevant and rigorously peer-reviewed insights on the opportunities and challenges present in the climate-development nexus with policy makers, the academic community, and a wider global audience.

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# Overview

Stabilizing climate change entails reducing net emissions of carbon dioxide ($CO_2$) to zero. This report outlines three principles to guide countries in their efforts to create a zero-carbon future: (a) planning ahead with an eye on the end goal; (b) going beyond carbon pricing with a policy package that triggers changes in investment patterns, technology, and behaviors; and (c) protecting poor people and avoiding concentrated losses. Although countries at different levels of income and with different endowments will adopt different strategies, all have a role to play.

Stabilizing climate change entails reducing net emissions of carbon dioxide ($CO_2$) to zero. $CO_2$ stays in the atmosphere for hundreds, if not thousands, of years. As long as we emit more than nature can absorb in its sinks (oceans, forests, and other vegetation), concentrations of $CO_2$ in the atmosphere will keep rising, and the climate will keep warming. And the decisions we make now will determine the planet's climate for centuries.

The latest science also tells us that we need to reach zero net emissions by 2100 to stabilize climate change around the 2°C target above preindustrial temperatures that has been agreed by governments as the maximum acceptable amount of warming. Relaxing the target to 3°C would make little difference in the policies needed, although a 2°C target would require more aggressive, earlier action.

But can we envisage a world in which economic activities have been made completely carbon neutral by the end of the century? Here, we should emphasize that *carbon neutrality* or *decarbonization* does not imply no emissions whatsoever. Positive emissions in some sectors and some countries can be offset, to some extent, through natural carbon sinks and negative emissions in other sectors and countries. So decarbonization means zero net emissions of $CO_2$—as well as the stabilization of emissions of short-lived greenhouse gases such as methane that dissipate in the atmosphere in days, weeks, or decades.

The latest report of the Intergovernmental Panel on Climate Change (IPCC)—which presents the consensus views of 830 scientists, engineers, and economists from more than 80 countries and was formally endorsed by the governments of 194 countries—identified many possible pathways to reach carbon neutrality by the end of the century. All require acting on four fronts: (a) decarbonization of electricity; (b) massive electrification (using that clean electricity) and, where that is not possible, a switch to lower-carbon fuels; (c) greater efficiency and less waste in all sectors; and (d) improved carbon sinks (such as forests, vegetation, and soil).

In practical terms, what does this mean for countries, especially developing countries that are already struggling to reduce poverty and achieve prosperity? Many are unable to keep up with the investments to satisfy the basic needs of their citizens, let alone the efficient cities, roads, housing, schools, and health systems they aspire to create. At the same time, the fact that much of their infrastructure is yet to be built means opportunities exist to act early and gain efficiency. Thus, the pursuit of a low-carbon transition must be integrated into the overall development agenda: the goal is not just to decarbonize, but to decarbonize development.

The aim of this report is to take this lofty goal of zero emissions by 2100 and examine what it means in terms of today's policy making for development. It does not discuss whether or why to stabilize climate change, or at which level we should do so. Our starting point is the 2°C goal set by the international community. We begin by examining how planning can help lay the foundation for both a stable climate and a good development path. Next, we explore how countries can create the right enabling environment so that the needed technology, infrastructure, and financing are available. Finally, we discuss how countries can carefully manage the transition, given the vital role that the political economy will play.

The message of this report is that to decarbonize development, and to do so by 2100, three broad principles must guide countries' low-carbon efforts:

- *Plan ahead with an eye on the end goal.* The appropriate way to achieve a given reduction in emissions by, say, 2030 depends on whether that is the final target or a step along the way to zero net emissions. If the latter, early action will need to be a mix of cheap, quick fixes and costlier long-term measures to promote technology development, investment in long-lived infrastructure, and changes in how cities are built. So every country needs to define a long-term target—say for 2050—that is consistent with decarbonization and to build short-term, sector-specific plans that contribute to that target and are adapted to the country's wealth, endowments, and capacity. The good news is that many options with high potential offer immediate local co-benefits, especially in low-income countries, so that early action need not represent a trade-off with short-term development goals.
- *Go beyond prices with a policy package that triggers changes in investment patterns, technologies, and behaviors.* Carbon pricing is necessary for an efficient transition toward decarbonization. It is also an efficient way to raise revenue, which can be used to support poverty reduction and development or to reduce other taxes. And a carbon tax can be designed to be administratively simple yet harder to evade than taxes on income or capital. But carbon pricing alone cannot solve the climate change problem, given the many market failures and behavioral

biases that distort economies. Policy makers also need to adopt measures such as targeted investment subsidies, performance standards and mandates, or communication campaigns that trigger the required changes in investment patterns, behaviors, and technologies—and if carbon pricing is temporarily impossible, to use those measures as a substitute.

- *Mind the political economy and smooth the transition for those who stand to be most affected.* Reforms live or die on the basis of how well the political economy is managed: a climate policy package must be attractive to a majority of voters and avoid impacts that appear unfair or that are concentrated in a region, sector, or community. Thus, reforms have to smooth the transition for those who stand to be affected—by not only protecting vulnerable people but also avoiding concentrated losses and sometimes compensating powerful lobbies. Fortunately, getting rid of environmentally harmful subsidies and pricing carbon provide additional resources with which to improve equity, to protect those affected, and, when needed, to appease opponents.

Of course, these are broad principles that every country will need to interpret in light of its own needs, institutions, and aspirations. Even so, a few generalizations can be made. Low-income countries, given their extremely low emissions levels, should focus on options that are consistent with immediate poverty alleviation and that do not stand in the way of short-term growth, including the adaptation and diffusion of technologies developed elsewhere. Richer countries can afford to implement more expensive measures and take the lead on developing frontier technologies such as carbon capture and storage and subsidizing their deployment so that the technologies improve and their cost decreases.

But all countries should work to avoid creating carbon-intensive lock-ins that will be costly to reverse later and to capture the large economic and health co-benefits from a cleaner and more efficient economic system. Further, income is not the only factor that differentiates countries. Countries that are rapidly urbanizing have a crucial window of opportunity to create cities that are energy efficient and easy to serve with public transit. Countries with large forests can achieve a lot by focusing on reducing irreversible deforestation. More generally, countries differ by the endowment of natural resources—for instance, their potential for hydropower or solar energy—and will therefore implement very different strategies. But, although countries will follow different pathways, all countries have a role to play.

## Planning for a Low-Carbon Future: What We Need to Do Now Depends on the End Goal

A key reason scientists believe it is possible to achieve full decarbonization by 2100 is that they have looked at pathways that would do so. Those pathways are derived from various energy and economic models that examine what it would take to achieve decarbonization under a number of different scenarios of economic growth and technological innovation. As mentioned earlier, what all models and modelers agree on is that action will be needed on four fronts:

- Decarbonizing the production of electricity
- Undertaking massive electrification (to increase reliance on clean electricity) and, where not possible, switching to cleaner fuels
- Improving efficiency and reducing waste in all sectors
- Preserving and increasing natural carbon sinks through improved management of forests and other vegetation and soils

The question is when to begin and at what speed to proceed. Fortunately, there is no need for all countries to follow the same path or rhythm. Weaker efforts early on can be offset (up to a point) by greater efforts later, and more effort now means less will be needed tomorrow. And since decarbonization is a global goal, greater efforts by a richer or more able country can offset less intense efforts by a country with less capacity. As the IPCC argues, multiple pathways can lead to decarbonization. However, the key to feasibility is affordability, and affordability requires early action.

## Early Action

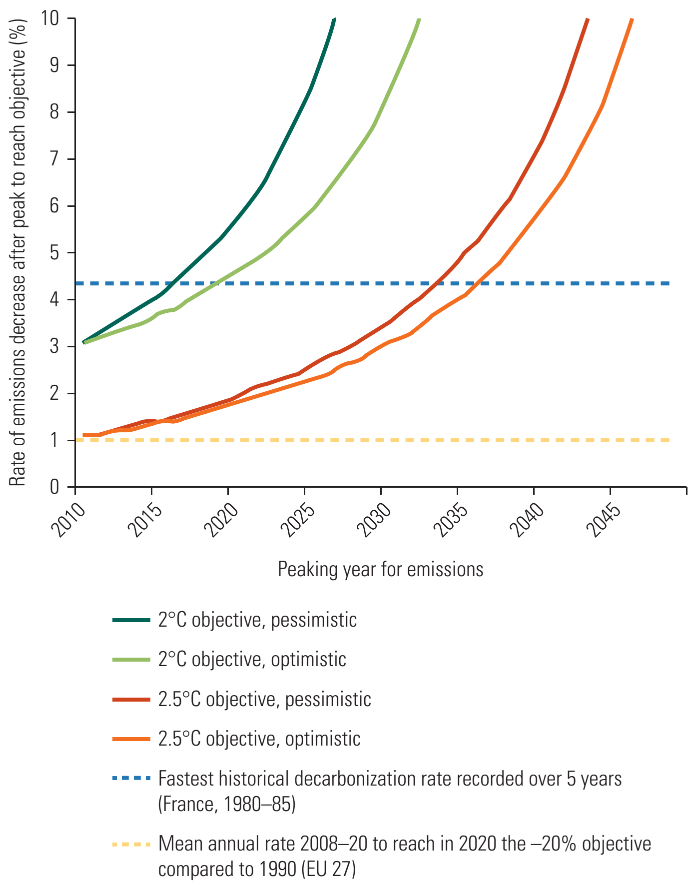
Early action is vital for two reasons. First, it is cost-effective, because it allows countries to take advantage of natural opportunities to green their capital as it is retired or as it is first built. The alternative is delays, which imply the continued construction of dirty power plants and other capital that create "committed emissions." For example, the fossil-fueled power plants built in 2012 alone will emit some 19 billion tons of $CO_2$ over their expected 40-year lifetime, more than the annual emissions of all operating fossil-fueled power plants in 2012. Retiring them early is possible, but costly. The models reviewed by the IPCC find that if mitigation is postponed until 2030, costs would rise an average 50 percent for the 2030–50 period, and 40 percent for the longer term (2050–2100).

Second, early action is prudent because delays can result in lock-ins and the loss of options. A failure to invest in developing new technologies such as carbon capture and storage now may mean they are not available by midcentury when they are needed. And trying to retrofit a low-density city to make it more carbon efficient and suitable for public transit is extremely difficult, as city managers around the United States are finding out.

Thus, the pledges made by member countries of the United Nations Framework Convention on Climate Change in Cancún in 2010 are worrisome: they amount to such modest reductions in the short run that they would require annual cuts in emissions of 6 percent per year from 2030 onward to achieve the globally endorsed stated objective of 2°C. Historically, such rapid declines have occurred only during economic collapses, such as the fall of the Soviet Union. The highest decarbonization ever achieved in a planned fashion was 4.5 percent per year, when France deployed its nuclear energy program (figure O.1).

Some will say that waiting can also save money: as technologies evolve, they improve, become more affordable, and open up new options. But if everyone waits, those technologies will not be invented, and they certainly will neither improve nor become more affordable. And in the face of development pressures, waiting is not always an option. Things get built anyway—but incorrectly, as is occurring in much of the urbanization taking place in developing countries.

**FIGURE O.1 The Tortoise and the Hare: Not Starting Early Will Entail More Drastic Emission Cuts Later**




*Source:* Adapted from Guivarch and Hallegatte (2013).

*Note:* Peak year refers to the year in which emissions have reached their highest level and start to decline. Delaying the peak year by just a few years, say from 2010 to 2020, entails increasing the rate of annual emissions reduction from 3 percent to 4.5–5.5 percent. The figure also reports the fastest historical decarbonization rate achieved over a five-year period (outside of periods of economic collapse) and the decarbonisation rate implied by the European Union's commitment between 2008 and 2020. EU = European Union.

So someone has to start. And when it comes to new technologies, the richer countries must lead in funding frontier innovation and creating the demand that allows for large-scale deployment and lower costs. Thus, the massive expansion in solar energy in Germany has been critical in reducing the cost of solar panels. But even very poor countries can identify early action that makes sense within their overall development strategy.

What exactly does early action entail? And how should policy makers make decisions in situations of uncertainty, multiple worldviews, and competing objectives? We would argue, as we did in *Inclusive Green Growth: The Pathway to Sustainable Development* (World Bank 2012), that countries should focus on actions that offer synergies with short-term development goals or that are urgent:

- *Synergies.* Many mitigation options (such as public transit, cleaner energy, and energy efficiency) offer immediate and local economic and welfare benefits. Prioritizing those options will help ensure that climate considerations are well integrated into countries' development plans and will increase political acceptability. For example, some analyses suggest that the health benefits of cleaner air alone would exceed the cost of mitigation in many regions at least until 2030 (Shindell et al. 2012; Thompson et al. 2014).
- *Urgency.* Some mitigation options are associated with high technical inertia (meaning that they carry a risk of lock-in, irreversibility, or higher costs if action is delayed)—such as unplanned low-density urban expansion or the cutting down of old-growth forests. Some abatement actions will take time and will need to be implemented early (such as research and development for the needed technologies and support for their deployment). For them, action is urgent. Otherwise, action can be postponed for measures that create hard trade-offs with other development goals in poor countries.

## Planning Ahead

The good news is that a number of planning tools are available to help countries—poor and rich alike—devise an appropriate decarbonization plan. But the key is to use these tools with an eye on the end goal for a number of reasons.

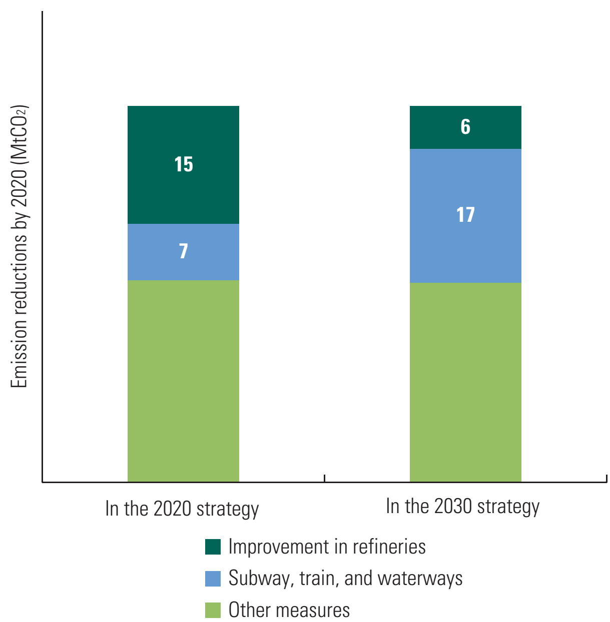
First, keeping an eye on the end goal will help poorer countries align development and poverty alleviation with climate policies. Higher emissions from better energy access or structural change in poor low-emission countries or regions should not be a concern as long as irreversible carbon lock-in is avoided (possibly by using urban plans and well-enforced building norms). Indeed, those countries should use low-cost options to maximize poverty reduction, which may include coal where solar power or hydropower is not possible or is too expensive. That said, they would still benefit from capturing the potential for low-cost renewable power (such as hydropower), avoiding energy waste, improving air quality, and creating a cost-efficient economic system (with appropriate energy pricing and performance standards).

In addition, for all countries, a focus on short-term targets (such as 2030) without considering long-term ones (such as for 2050 and beyond) would lead to emission reductions based on the cheapest options—which may lack the potential to achieve complete decarbonization. It could thus result in a carbon-intensive lock-in, making it much more expensive to achieve the long-term objective.

Take the case of a low-carbon strategy analysis done for Brazil. As figure O.2 shows, the optimal strategy for a 2020 end goal makes greater use of marginal actions that are cheap and easy to implement but that have a limited potential (improved energy efficiency in refineries). In contrast, the optimal strategy for a 2030 end goal entails more ambitious actions that are more expensive and take longer to implement but that have the potential to contribute to deeper decarbonization. Thus, if the goal is simply a 10 percent reduction in 2020, limited use should be made of investments in subways, trains, and waterways—although those investments are critical to ensure the feasibility of a 20 percent reduction by 2030.

The key to designing an emission-reduction plan that accounts for the long term is to consider three characteristics of each option: cost, mitigation potential, and time needed to implement. Options with "negative costs" (such as energy efficiency) or large development co-benefits should be implemented as soon as possible. But as figure O.3

**FIGURE O.2 Using a Longer Time Frame Changes the Optimal Policy Mix for Brazil**




*Source:* Adapted from Vogt-Schilb, Hallegatte, and de Gouvello (2014).

*Note:* The 2020 and 2030 bars amount to an equivalent amount of emission reduction, although they include a different mix of measures; $MtCO_2$ = million tons of carbon dioxide.

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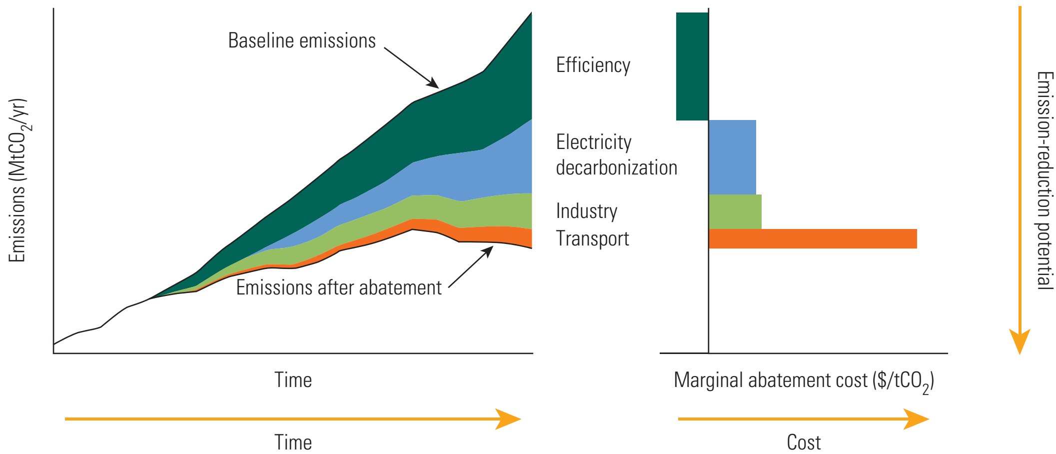
**FIGURE O.3 Devising a Strategy Requires Information on Time, Cost, and Emission-Reduction Potential**




*Note:* The "wedge curve" on the left shows emission-reduction potential as well as the time it takes to roll out a particular option (such as efficiency or electricity decarbonization). It is combined with a marginal abatement cost curve that shows emission-reduction potential and their cost, so that the three key dimensions of emission-reduction options—time, cost, and potential—can be displayed simultaneously. Numbers displayed are purely illustrative. The two graphs are certainly not sufficient to develop a full strategy. More information is needed on obstacles to implementation (such as why negative costs options have not been implemented already), but they do help highlight the need for looking at the three key dimensions simultaneously.

illustrates with a fictional example, options that are expensive but that are slow to reach their full potential (such as transport) may also have to get started early in order to reach the long-term goal. In contrast, cheaper options may be delayed—in figure O.3, electrification is cheaper than transport but can be introduced later without threatening the long-term goal.

With this information, governments can design operational short-term targets to ensure that they make progress in all sectors. For instance, a target may be to produce 30 percent of electricity from renewable sources by 2030, to drive cars that emit less than 80g$CO_2$ per kilometer by 2025, or to use wood materials—from sustainably managed forests—instead of steel and cement in half of all new buildings by 2035. This sectoral approach has an advantage over economy-wide emission goals, because the latter could be achieved with marginal actions that do not contribute sufficiently to meeting the long-term objectives.

## Enabling the Transition with a Policy Package That Is Efficient, Acceptable, and Credible

Good planning is important, but so are incentives and policies that ensure planned actions are implemented and projects are financed. Thus, carbon pricing is a critical policy, as it addresses a major market failure—the failure to price the environmental damage caused by greenhouse gases. However, a multiplicity of market and government failures comes together to make climate change a complex problem to solve. So pricing is necessary, but not sufficient, especially if a low-carbon strategy is to be politically acceptable and credible enough to trigger the kind of long-term investments that are needed. Also needed are complementary measures to make individuals and firms more responsive to prices—or substitutes for prices when they are ineffective.

## Getting Prices Right—Good Economic and Fiscal Policy

Schemes to get prices right have the great advantage of raising revenues in an economically and fiscally efficient way, making them good fiscal policies, in addition to their environmental benefits. That advantage is obvious with the elimination of environmentally harmful subsidies, but it is also the case for carbon pricing—whether taxes or cap and trade (provided that permits are sold or auctioned).

Getting prices right includes reforming fossil-fuel subsidies—which reached about $548 billion in 2013, according to the International Energy Agency, a number that is likely to be an underestimate. Even so, this sum still averages a whopping 5 percent of gross domestic product and 25–30 percent of government revenues among the 40 mostly developing countries for which it was calculated (IEA 2014). In addition, the Organisation for Economic Co-operation and Development estimates that its member countries spent $55–$90 billion a year in the 2005–11 period (OECD 2013). Other environmentally harmful subsidies, such as agricultural support schemes that incentivize the overuse of pesticides and fertilizer and excessive emissions, need to be reformed as well.

Encouragingly, good progress has been made in recent years. Over the past two years, more than 25 countries, many in Asia, have significantly reformed their fossil-fuel subsidies. Indonesia abandoned a four-decades-old policy of subsidizing gasoline, India liberalized diesel prices and raised fuel taxes, and Malaysia eliminated subsidies on gasoline and diesel. That trend is likely to accelerate with the drop in oil prices, which makes it easier to reform subsidies for oil importers and creates pressure for reform among oil exporters. And Europe is finally overhauling its common agricultural policy to largely eliminate environmentally harmful subsidies.

As for carbon pricing, it is also gaining momentum—with some 39 national and 23 subnational jurisdictions globally having implemented or scheduled to implement carbon-pricing instruments. For example, China has seven local emission-trading pilots to test possible approaches to a national scheme, and British Columbia, one of Canada's fastest-growing provinces, introduced a carbon tax in 2008.

Carbon pricing offers a potential "double dividend" by providing both environmental benefits and the possibility of reducing more distortionary taxes (such as those on labor or capital) by recycling carbon revenues. In addition, carbon constitutes an excellent tax base, as carbon sources are concentrated and difficult to evade. In the United States, for example, tax collection covering 80 percent of emissions could be accomplished by monitoring fewer than 3,000 points (refineries, coal mines, and natural gas fields) (Metcalf and Weisbach 2009). In Sweden, which has had a carbon tax since 1992, tax evasion is less than 1 percent for carbon, much less than for the value added tax. In the United Kingdom, evasion on energy taxes is about 2 percent, much lower than the 17 percent for income tax. That is a substantial advantage for the many developing countries that struggle with tax evasion—and the wedge it introduces between the formal and informal sectors.

Yet another way to get prices right is with performance-based payments, which can be used to create incentives to preserve or increase carbon sinks, such as forests and soil. Currently, more than 300 payments for ecosystem service schemes have been established worldwide, many of them for carbon sequestration. International incentive mechanisms—such as reducing emissions from deforestation and forest degradation and other forest-based mitigation activities (also called REDD+) are being developed.

### Policies to Complement Prices or to Substitute for Them When They Are Ineffective or Unchangeable

But getting prices right is not enough to ensure that low-carbon policies are acceptable, credible, and effective. Instead, policy packages need to take into account the following issues:

- *Are prices an effective instrument to trigger the desired change?* The answer depends on such factors as the availability of low-carbon alternatives or the need for long-term credibility. For instance, a carbon tax is sufficient to trigger fuel shifts in the energy sector (maybe from coal to gas) but may not be enough to generate frontier innovation in the energy or automobile industry.
- *Is it possible to change prices?* Whether prices can in fact be changed enough to trigger a response depends on the political or social acceptability of a price change. The issue may be concerns about the impact on poor people or the need to manage powerful lobbies fiercely opposed to reform.

Those two issues are linked. If price effectiveness is low, reducing emissions to a given level would require a significant price hike, which is more likely to hurt some groups or industries and is thus less acceptable. It is also possible that prices can be changed without leading to the expected impact on emissions because of missing markets, lax compliance, lack of information, or behavioral biases and cognitive failures. As a result, the policy package will need a battery of instruments—such as research and development and innovation support, performance standards and fiscal incentives for investments, financial instruments, and social policies and compensation—to create an enabling environment for the low-carbon policies to work. This requires efforts on the following fronts.

***Ensure needed technologies.*** A first challenge is to ensure that the needed technologies exist (a pure innovation problem) and are available at scale and at a competitive cost (a deployment problem). Existing technologies are sufficient to keep the world on a 2°C path up to about 2050, but thereafter, staying on track will require deploying technologies that are currently barely at the pilot stage or do not even exist. And the claim that a 2°C path is affordable relies on the assumption that the needed technologies will be available.

Green innovation suffers from a double market failure—environmental externalities and the same "knowledge externality" that plagues all innovation (new knowledge can be acquired at low cost by competitors). But a combination of a carbon price and broad public support for innovation will not be sufficient. Specific support toward green innovation is essential. Economic actors prefer to innovate where they have innovated before and where there is a combination of well-known demand and mature markets—a bias that favors marginal innovation in traditional domains, not radically new green innovation. Also, a carbon price is unlikely to be a sufficiently credible instrument to justify the kind of long-term, risky investments that are required for green frontier innovation. Policy makers should kick-start the transition either by temporarily supporting investments in low-carbon technologies (Acemoglu et al. 2012) or by imposing additional regulations or performance standards (Rozenberg, Vogt-Schilb, and Hallegatte 2014).

In addition, governments may even need to target specific green technologies. That specificity is justified in the case of solar, which is still more expensive than wind energy in most markets but has greater potential for reducing cost through economies of scale and for addressing the clean-energy challenge. Because of solar's current relatively high costs, it is unlikely to be massively deployed with only horizontal (nontargeted) support to carbon-free electricity production or a carbon price.

To ensure that green technologies are invented and deployed at scale, countries might supplement carbon prices (or substitute for them where they cannot yet be implemented) with a number of instruments:

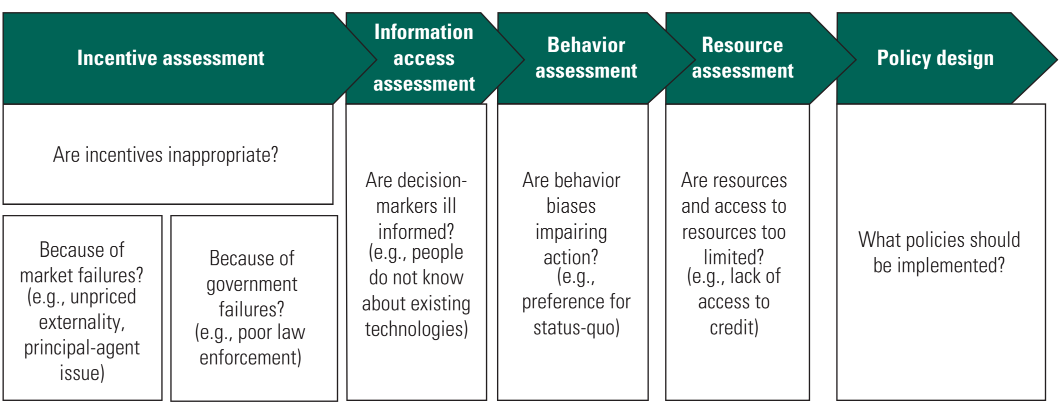
- Performance standards—such as those commonly used for cars in China, the European Union, and North America, and energy-efficient lighting or building codes (windows, ventilation, or heating and cooling systems).
- Fiscal instruments—such as auto *feebates*, which combine a surcharge (fee) on energy-inefficient cars with a rebate on more energy-efficient ones (used, for example, in a number of European countries) or a value added tax exemption for appliances or energy-efficient lighting (used, for example, in China, Ghana, and Tunisia).

- Mandates—such as renewable portfolio standards that require electricity providers to include a minimum share of clean energy in their output mix. Mandates have been used throughout the world, notably in Chile, China, Germany, and many U.S. states.
- Trade policies—such as cutting tariffs on green goods, such as solar panels, wind turbines, and energy-efficient lightbulbs as Asia Pacific Economic Cooperation countries recently agreed to do—to ensure that countries, firms, and households can access the best technologies that are available globally at an acceptable cost.
- Better institutional capacity and law enforcement—such as clarifying property rights and increasing controls and fines. In Brazil, enforcing and clarifying existing laws have proved to be an effective, low-cost strategy to reduce deforestation.

***Ensure the needed infrastructure.*** Providing the needed infrastructure is critical for both the effectiveness of low-carbon strategies and the political acceptability of carbon pricing. For example, imposing significant fuel taxes has proved a lot more difficult in the United States than in Europe, in part because a much larger share of U.S. voters live in places unserved by easy, convenient public transportation. Infrastructure also makes a carbon price more effective by making demand more elastic to price changes. A modeling exercise for Paris shows that public transport reduces by half the carbon tax needed to achieve a given emission reduction (Avner, Rentschler, and Hallegatte 2014). Similarly, some countries have struggled to ensure that the needed electricity transmission lines and network capacity are in place to handle increased shares of renewable energy.

***Account for behavioral biases and other obstacles to changing habits.*** But even with price incentives and available alternatives, people may still stick to old habits for a variety of reasons (figure O.4). They may do so because incentives are not effective due to

**FIGURE O.4 How to Assess the Obstacles to Low-Carbon Solutions**




*Source:* Adapted from World Bank (2013).

some market failure (for example, landlords who buy inefficient equipment because tenants pay the electricity bills) or because the incentives are just not enforced. Many countries have enacted energy-efficiency requirements for new buildings without implementing measures to enforce them.

People may also not be aware of better alternatives. Labels and certification schemes can easily provide the information consumers need to influence production technologies and promote sustainable natural resource management (for instance, for forest management).

Evidence abounds of people being “tempted” by the low price of an appliance and not paying attention to the lifetime cost of a purchase. And people tend to stick to the default option. Such behavioral biases can in fact be used to increase the adoption of green technologies. For example, a German energy company found that 94 percent of its customers stayed with the green (and more expensive) option when it was set up as the default, and only 4 percent opted for a cheaper one (the remaining 2 percent either changed suppliers or opted for a more expensive green option).

### Getting the Finance to Flow—Which Will Take More than Carbon Pricing and Green Finance

Making the needed infrastructure and technologies available requires financing. In fact, most developing countries struggle with financing infrastructure provision and technological development and deployment even without the low-carbon objective. Fiscal limits constrain self-financing and overseas development aid, so the bulk of the finance challenge lies with making sure that developing countries can access more private (domestic and international) resources for long-term investment. That financing constraint extends to developing-country firms, especially small and medium-sized firms, many of which would need to invest in energy-efficient and low-carbon equipment and to access technologies adapted to local conditions.

The challenge thus is twofold: (a) to increase financing for investments in developing countries and in long-term projects, notably infrastructure, and (b) to increase the share of those investments that goes toward green projects. The low-carbon part of that challenge is an important one but should not be overestimated. According to the models reviewed by the IPCC, estimates of needed additional investment average about $400 billion per year, or about 0.5 percent of global gross domestic product. Another estimate places it at about $300 billion out of a yearly average of $6 trillion needed for overall investments by 2030 (NCE 2014).

That amount is far from negligible, but it is a small share of the total needed anyway for development and growth. Further, those investments would generate co-benefits beyond reduced climate change impacts, such as reduced air pollution that would avoid 1 million premature deaths annually by 2050 (West et al. 2013), improved agricultural productivity, increased access to public transit, reduced congestion and traffic accidents, and greater energy security for fossil-fuel importers.

Of course, investment needs could be higher or lower, depending on how technologies develop, how early we start, and how efficient the transition is. At the sectoral level, the IPCC reports a possible range of $31 billion to $360 billion in annual investment needed for low-emission-generating technologies (renewable, nuclear, and fossil fuels with carbon capture and storage) between 2010 and 2029 and a possible range of $1 billion to $641 billion per year in energy-efficiency investments in the building, transport, and industry sectors over the same period.

Nevertheless, the point remains that the real challenge is likely to be access to financing, rather than affordability per se. Even if the absolute cost is modest relative to overall resources and represents a small increase in overall needs, financing could be difficult for countries that already struggle to generate the needed basic investments.

How can the existing financing gap be closed? Recommendations typically fall into two broad categories: making the investments more attractive and leveraging private resources to make the most of available capital. Those approaches involve well-known steps, such as improving the investment climate (making sure that regulations are clear and predictable and that the rule of law and property rights are enforced), developing local capital markets, and providing a pipeline of *bankable* projects—something that has proved difficult for many countries and is now recognized as an even greater challenge than a lack of capital. But closing the financing gap most likely also requires a deep reform of the international monetary system, including financial sector risk assessment and stress tests that have a longer time horizon and consider a broader set of risks (such as carbon exposure), along with compensation packages more attuned to long-term returns and risks.

In addition, low-carbon investments present a number of issues that must be addressed with targeted tools. Initial investments for low-carbon projects tend to be a higher share of total costs than for conventional projects, making them more sensitive to financial costs. Low-carbon projects tend to carry greater technology risk, simply because they typically rely on newer technologies. They also have higher policy risks, to the extent that they may be more dependent on government policies (such as a carbon price). In some cases, they may just be new and different, requiring investors and project managers to innovate, and may possibly lead to a *perception* of higher risk.

Thus, we see the need for rebalancing both the actual and perceived risk-adjusted returns differential between brown and green projects. The most powerful way of reducing risk perception is to make progress toward global agreements and the design of an international architecture to support climate change mitigation. That approach will go a long way toward convincing economic actors that the future will be carbon neutral. In addition, adding environmental considerations into banks' due diligence standards would help make the financial system more sensitive to the risks embedded in *carbon-entangled* investments. As an example, the Bank of England recently agreed to examine the vulnerability that fossil-fuel assets could pose to the stability of the financial system in a carbon-constrained world.

In addition, the development of green financial products (such as green bonds) is helping mainstream low-carbon investments, connect green project developers with possible investors, and overcome the behavioral bias toward conventional investments. The green bond market has experienced rapid growth—reaching some $35 billion in 2014, up from $12 billion the year before—thereby contributing to the reallocation of resources from traditional investments to low-carbon ones. It is gaining further momentum with the development of green bond indexes by heavyweights such as Standard & Poor's, Bank of America, and Merrill Lynch.

With regard to high financial costs linked to low-carbon projects, they can be reduced through cofinancing by governments or multilateral development banks that may want to take on the *green* part of the risk. Investments can also be redirected with bank regulations that encourage commercial banks to invest in low-carbon projects. The rationale for such policies comes from the diverse mandates of central banks, which range from simply achieving price stability to contributing to wider economic and social objectives.

## Managing the Transition: Protecting Poor People and Avoiding the Potential Pitfalls of Reforms

The goal of the transition is to decarbonize development rather than just reduce emissions. Hence, reforms must contribute to poverty alleviation and shared prosperity. And as with any major transition, the political economy of reforms must be managed with allowances made to those with a stake in the status quo and with good communication of the goals and benefits of the reform.

### Ensuring Poor People Benefit

Fossil-fuel subsidies and artificially low energy prices are not efficient ways to boost competitiveness or help poor people. Such measures drain fiscal coffers, hurt the environment, slow the deployment of greener technologies, and chiefly benefit nonpoor people. A review of fossil-fuel subsidies in 20 countries shows that the poorest 20 percent of the population receive on average less than 8 percent of the benefits, whereas the richest 20 percent capture some 43 percent (Arze del Granado, Coady, and Gillingham 2012).

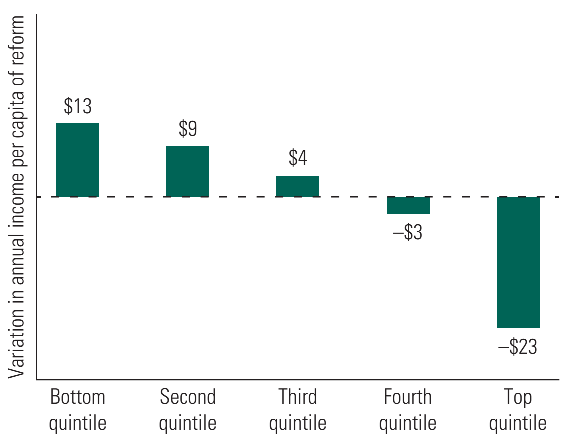
But even if removing fossil-fuel subsidies and adopting carbon pricing improve equity, those measures will also increase the price of energy and other goods (such as food), thereby reducing poor households' purchasing power. Further, higher prices for modern energy could lock poor people into using solid fuels for cooking, with impacts on health, gender balance, and children's access to education (women and children spend a disproportionate amount of time collecting traditional fuels and spend more time exposed to indoor pollution). Also, industrialization has been a powerful force for poverty reduction in many countries and could theoretically be slowed by higher energy prices.

It is therefore critical to use the savings or new proceeds generated by climate policies to compensate poor people, promote poverty reduction, and boost safety nets. One way to do that is by recycling revenue through tax cuts and increasing transfers to the population—as British Columbia did to ensure that its reforms were progressive (Beck et al. 2014). Similarly, the Islamic Republic of Iran implemented a quasi-universal cash transfer (about $45 per month per capita) as part of its energy reforms (IMF 2013). A modeling exercise carried out using data from developing countries shows that taking $100 away from fossil-fuel subsidies and redistributing the money equally throughout the population would on average transfer $13 to the bottom quintile and take away $23 from the top quintile (figure O.5).

Another way to ensure that poor people benefit is with in-kind measures. Ghana's 2005 fossil-fuel subsidy reform increased the price of transport fuels by 50 percent but also included an expansion of primary health care and electrification in poor and rural areas, the large-scale distribution of efficient lightbulbs, public transport improvements, and the elimination of school fees at government-run primary and secondary schools (IMF 2013; Vagliasindi 2012).

**FIGURE O.5 Using Fossil Fuel Subsidy Resources for Universal Cash Transfers Benefits Poor People**

*(Impact of recycling $100 from a fossil fuel subsidy to a universal cash transfer)*




*Source:* Based on Arze del Granado, Coady, and Gillingham (2012).

*Note:* The figure shows the impact of reducing the fossil-fuel subsidy budget by $100 and distributing the savings as a universal cash transfer.

Redistribution has also been shown to significantly increase the odds of reforms succeeding. A review of reforms in the Middle East and North Africa classifies all reforms with cash and in-kind transfers as successful, as opposed to only 17 percent of the cases without (IMF 2013; Sdralevich, Sab, and Zouhar 2014).

Similarly, care must be taken in the design of land-use-based mitigation policies to ensure that they do not restrict access to land for the poorest people and that they respect and strengthen customary rights. A good example is Brazil's Terra Legal program, which is offering formal recognition to indigenous land and granting land titles to some 300,000 smallholders. Without such a program, REDD+ policies may benefit only richer landowners. In addition, payment for ecosystem services can directly increase the incomes of poor land users. Such programs in Brazil, Ecuador, and Guatemala aim to support poor communities, although so far evidence of their impact is limited. The hope is that by 2030, an estimated 25 million to 50 million low-income households will benefit if carbon payments are fully developed and pro-poor participation conditions secured (Milder, Scherr, and Bracer 2010).

### Managing the Political Economy of Reform without Getting Captured by Vested Interests

Worries about large-scale deindustrialization and job losses—which play a big role in debates on carbon tax and cap-and-trade systems—may be overblown. Evidence from developed countries suggests that there are no discernible impacts on productivity and jobs from introducing cost-increasing environmental regulations or pricing schemes.

Indeed, pollution abatement costs represent only a small fraction of production costs for most industries, and factors such as the availability of capital and skilled labor or proximity to markets are much more important determinants of firm location and competitiveness (Copeland 2012). A detailed analysis of the European iron and steel industry shows that the impact of the European Union's emissions-trading scheme remains limited, with impacts smaller than interannual exchange rate variations (Demailly and Quirion 2008). In contrast, resources raised by carbon-pricing schemes can contribute to attracting more jobs and investments by improving more important factors, such as education and workers' skills or infrastructure, and by reducing capital and labor taxes that are more distortive than carbon pricing.

However, what is valid for relatively modest environmental regulations may not be true for stricter policies. A low-carbon transition entails a shift away from carbon-intensive sectors and technologies toward low-carbon ones. In the short to medium term, that transition means reallocating capital, labor, and rents. It cannot be done without negative impacts on some asset owners and workers. Further, those impacts may be spatially concentrated in regions that specialize in energy-intensive or extractive industries, such as steel production or coal mining.

A key question is the extent to which those who stand to be most affected need to be compensated or protected. The answer can be based on ethical considerations: poor people are vulnerable to those changes and have a lower capacity to adjust to price changes; and some (poor or non-poor) stand to lose their investments and livelihoods because the rules of the game have changed, not because they were willfully doing the wrong thing. But there is also a pragmatic argument: compensation may be needed for political economy reasons. Climate policy gains tend to be diffuse across economic actors, and the benefits of climate change stabilization are intangible *avoided losses*, which take place mostly in the future. Those characteristics do not help create a vocal group of policy supporters (Olson 1977). In contrast, policy costs tend to be visible, immediate, and concentrated over a few industries, which may have a de facto ability to veto the reform.

A number of steps can help smooth the transition and avoid concentrating losses (either spatially or within a particular interest group). One option is to start the reforms with regulations such as performance standards that apply only to new capital. This approach is less efficient from an economic point of view than immediately introducing a carbon price. But it has the advantage of putting the economy on the right path without hurting owners of existing capital (hence, reducing resistance). Further, it creates a constituency for change, as business owners are less likely to lobby for repeal of a carbon law or against the subsequent introduction of a carbon tax if they have already invested in the new, cleaner capital. So the impact of a regulatory approach can extend past the existing election cycle. This approach also delivers emission reductions and—maybe most important in places with highly distorted prices—prepares the economy for the introduction of a carbon price or the removal of fossil-fuel subsidies, as it progressively transforms the economic system into a more efficient one that remains competitive with appropriate energy prices (Rozenberg, Vogt-Schilb, and Hallegatte 2014).

Another solution is to adopt compensation schemes. Strong social protection systems play the role of *horizontal* compensation systems, since they protect households and individuals against economic shocks. Specific instruments can also be implemented, as in Japan's support for traditional industries (such as textiles and shipbuilding) in the 1960s and 1970s. Japan relied on fiscal policies and, starting in 1978, planned capacity reduction, providing assistance to troubled firms and mitigating negative impacts on labor (Krauss 1992; Peck, Levin, and Goto 1987). The U.S. Trade Adjustment Assistance Program also provided reemployment services to displaced workers and financial assistance to manufacturers and service firms hurt by import competition. Experience from trade liberalization has shown that support such as wage subsidies to encourage hiring in the expanding sectors and unemployment insurance for the displaced workers can effectively help mitigate most of the losses and have generally modest costs (Porto 2012; Trebilcock 2014).

Of course, governments make mistakes when trying to smooth the transition—by erring when they try to *pick the winners*, by supporting declining sectors beyond what is efficient, or by being captured by special interests. Thus, they have often taken steps to help reduce the likelihood of costly failures and capture. For example, East Asian governments used trade competitiveness as a marker for their industrial policies: public support was swiftly cut for industries that could not compete in international markets. Such a clear test may be more difficult for low-carbon technologies that by nature depend on a government policy to be attractive (whether carbon price or a regulation), but, in general, the following can help (Rodrik 2013):

- Clear and transparent criteria that determine when public support should be terminated
- An institutional design that balances flexibility (needed to adjust policies when new information is available) and predictability (so that long-term investment is possible)
- Transparency and public accountability—so that the beneficiaries of the policies are the public rather than the firms that are being supported

### And Finally, Communication Matters

The political acceptability of reforms does not depend just on their impact. The *perception* of impact also matters. Thus, reforms must be anchored in a good understanding of who the stakeholders are and the nature of their fears and concerns.

Take the case of fossil-fuel subsidy reforms. A 2014 survey in the Arab Republic of Egypt showed that a whopping 70 percent of the population did not know the scale of the subsidy; worse, in Morocco, a 2010 survey found that 70 percent were unaware that energy was in fact subsidized. Thus, it was vital to raise awareness about the fact that the subsidy absorbed a huge part of government revenues (39 percent in Egypt and 17 percent in Morocco)—and the many other things that the government could achieve with those resources. Where reforms have been successful, they have often been accompanied by a communication campaign that spoke to citizens' concerns about "what's in it for me?" For example, the message of the Islamic Republic of Iran's 2010 fuel reform campaign was that the reform aimed to switch subsidies from *products* to *households*.

Wording also matters. Calling a carbon-pricing scheme a carbon *tax* suggests that its purpose is primarily to raise revenues rather than to improve welfare by creating incentives to produce and consume fewer carbon-intensive products. In fact, most schemes avoid using *carbon*, *climate*, or *tax* in their official labels, instead opting for terms such as *fee*, *premium*, or *surcharge* (Rabe and Borick 2012).

Finally, the broader benefits of reform must be communicated. In Germany, a study found that businesses were aware of higher energy taxes but not of the associated cuts in payroll taxes. But once they were informed, they were less likely to disapprove of the energy tax (Dresner et al. 2006).

## In Conclusion

This report explores the types of climate policy packages needed to achieve a complete decarbonization of our economies by 2100, taking into account the many market failures, imperfections, risks, undesired distributional effects, and political economy obstacles that such a deep transition entails. It also offers a possible road map for countries that are planning their transition toward full decarbonization.

***Plan ahead with an eye on the end goal.*** As a first step, those countries need to set up long-term objectives—say to 2050—that are consistent with the end goal of full decarbonization. Although those objectives need not be commitments, they make it possible to work backward and identify what needs to be done immediately to avoid locking in carbon-intensive patterns and increasing the odds of costly changes later on. At the same time, countries need to identify mitigation actions that bring economic, social, or health co-benefits and are therefore desirable for development and improved welfare.

From there, countries can design sector-specific shorter-term targets—to 2025 or 2030—and establish a way to track progress on the four pillars of a zero-carbon strategy: (a) decarbonization of electricity, (b) massive electrification and a switch to cleaner fuels, (c) improved efficiency and reduced waste in all sectors, and (d) improved carbon sinks. A short-term goal expressed as an economy-wide emission target is also useful but cannot replace the sectoral targets, since it could be reached with marginal actions that do not contribute sufficiently to meeting the long-term goal.

***Go beyond prices.*** Then, countries need to craft a comprehensive policy package that includes the following elements:

- Getting prices right—including pricing carbon, which is both good fiscal and environmental policy—represents an efficient way to raise resources and can be designed to be easier to administrate and harder to evade than other taxes. It is relevant for countries at all income levels, provided that it raises revenues and that those revenues are used to support poor and vulnerable people, to reduce distortive taxes on labor and capital, and to invest in the future (such as in infrastructure or education).
- Measures to complement (or, if need be, substitute for) carbon pricing. Innovation incentives will be crucial in countries at the technology frontier. Labels, performance standards, fiscal incentives, and financial instruments have proven track records in countries at all income levels and can ensure that the best technologies are deployed to reduce energy demand and carbon emissions.

Those instruments are not only more efficient than a carbon price in triggering behavioral changes in some sectors, but they also reduce the level of the carbon price that is needed to achieve decarbonization, making it more acceptable, credible, and realistic. And making financing available will be key to implementation.

***Protect poor people and avoid concentrated losses.*** Finally, the policy package must also include measures that make it attractive for the broader population and that avoid impacts that appear unfair. Understandably, analyses of climate policy packages typically focus on the design of the climate side of the package—the pricing instruments, the role of regulation and norms, and the support to innovation and green technology. However, the review undertaken in this report suggests that a large share of the challenge lies in the political economy. Success in stabilizing climate change will be largely determined by the ability of those accompanying policies to ensure that the decarbonization of the economic system contributes to economic development and the sustainable eradication of poverty.

Decarbonizing development is necessary to stabilize climate change. All countries are well-advised to start now, but not all will. Some countries will choose to embark on this journey sooner than others. To those countries, our message is that starting early in keeping an eye on the end goal is the way to go, along with a policy package that goes beyond prices to trigger changes in investment patterns, technologies, and behaviors and that smooths the transition for those who stand to be most affected—keeping in mind that political economy is what reforms live or die by.

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# PART I

## Planning for a Low-Carbon Future: What to Do Now Depends on the End Goal

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# 1. Reducing Carbon Emissions to Zero

- Stabilizing climate change at any reasonable level requires reducing net carbon dioxide ($CO_2$) emissions to zero by 2100.
- Decarbonization pathways involve progress along four fronts: (a) electricity decarbonization, (b) electrification, (c) increased energy efficiency, and (d) preservation and increase of natural carbon sinks such as forests and other vegetation and soils.
- Countries can proceed at different speeds across those four fronts to suit their political and economic realities, but significant progress will eventually be required on all four in all countries.

In recent years, the international community has agreed to hold global warming to about 2°C above preindustrial levels. The latest scientific findings tell us that to reach that target, all countries as a group must reduce $CO_2$ emissions to zero by 2100—although rich and poor countries can proceed at different paces, and some will still be able to have positive emissions as long as others have negative ones.

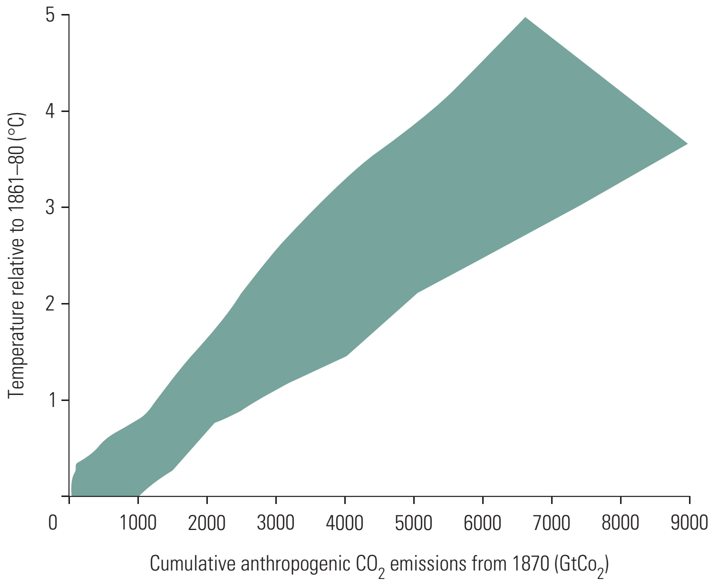
This chapter examines where the science stands and identifies measures—both from the recent report of the Intergovernmental Panel on Climate Change (IPCC) and other studies—that are robust in the sense that they will not be regretted later on.

## Stabilizing the Climate Requires Zero Net Emissions

Arguably the most important message to emerge from climate research is that in order to stabilize climate change, net emissions of $CO_2$—the most important of the so-called long-lived greenhouse gases (GHGs) that stay in the atmosphere for centuries—must be reduced to zero. As long as human societies release $CO_2$ in quantities greater than carbon sinks such as forests and other vegetation can absorb, the climate will continue changing (IPCC 2014; Matthews and Caldeira 2008).[1]

However, the issue is not just to stabilize the climate, but the level at which we do so. The level is largely determined by the emissions of $CO_2$ accumulated over time (figure 1.1). The greater the cumulative emissions, the warmer the climate. So the quicker we achieve decarbonization (shorthand for reducing net emissions of $CO_2$ to zero, also referred to as carbon neutrality), the greater our chance of keeping warming at a reasonable level.

**FIGURE 1.1 Rising Cumulative Emissions of $CO_2$ Mean Rising Temperatures**




*Source:* Adapted from IPCC (2014).

*Note:* Graph shows the almost-linear relationship between total $CO_2$ emissions starting in 1870 and the change in global temperature.

The level at which the temperature is stabilized also depends on the concentrations of short-term GHGs. In contrast with $CO_2$, however, concentrations of short-term GHGs can be changed rapidly if emissions are reduced (box 1.1). Although that is certainly part of the decarbonization story, policies targeting short-term GHGs are not the topic of this report (on this issue, see Akbar et al. 2013).

Another key area of scientific consensus is that carbon neutrality is needed by 2100 if we hope to stabilize the climate anywhere below 3°C (figure 1.2). Moreover, achieving the 2°C target will necessitate negative emissions—that is, removing $CO_2$ from the atmosphere—in the second part of this century. Negative emissions can be achieved through increased natural carbon sinks—such as reforestation, which captures atmospheric $CO_2$ and stocks it as vegetation. It can also be done using specific technologies, such as biofuels used in power plants combined with carbon capture and sequestration (CCS).

Importantly, carbon neutrality is a global target, as a unit of $CO_2$ emitted anywhere in the globe has the same warming potential. Not all countries need to achieve zero net emissions at the same time. Countries have room to maneuver as they move toward the objective of zero net emissions, taking into account their income and development levels. In most of the IPCC scenarios that achieve carbon neutrality, positive emissions in some countries are balanced by negative emissions in others.

### BOX 1.1 The "Full" Story on Greenhouse Gases

Greenhouse gases (GHGs) are composed of long-lived gases, mostly carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$), which can stay in the atmosphere for hundreds, if not thousands, of years, and short-lived gases (such as black carbon or soot, methane, and most hydrofluorocarbons), which stay in the atmosphere for much shorter periods, from days to decades. The concentration of $CO_2$ depends on the cumulative emissions over time—the sum of the emissions made in the past: it keeps increasing as long as emissions are positive, and it decreases only over centuries if emissions are brought to zero. The concentration of short-lived GHGs is proportional to annual emissions: a reduction in emissions rapidly leads to a reduction in concentration.

Those vastly different time frames mean that stabilizing GHG concentrations requires that both of the following occur:

- Bringing net emissions of $CO_2$ and $N_2O$ to zero, given that their atmospheric concentration increases as long as net emissions are positive; and
- Keeping emissions of short-lived GHGs constant, given that their atmospheric concentration stabilizes almost as soon as emissions stop increasing.

The level of warming depends on the overall concentration of those GHGs in the atmosphere, which is determined by the cumulative emissions of $CO_2$ over time and the annual emissions of short-lived GHGs.

As figure 1.1 illustrates, there is a range in the temperature change that is associated with a given level of cumulative $CO_2$ emissions. For example, cumulative emissions of 3,000 gigatons of $CO_2$ ($GtCO_2$) would lead to a temperature increase of between 1.0°C and 2.5°C. That range reflects the uncertainties that surround both the concentration of short-lived GHGs and the response of the carbon and climate system to emissions of $CO_2$ and other GHGs. Because of those uncertainties, cumulative emissions or concentrations of $CO_2$ do not translate into a given temperature increase but into ranges, usually expressed by the likelihood of not exceeding a particular level of warming. For instance, total emissions of 3,000 $GtCO_2$ would maintain the temperature change below 2°C with a probability of 66 percent. So within that limit, there is still a 34 percent chance of missing the 2°C target.

## Zero Net Emissions Requires Action on Four Fronts

What needs to happen for world economies to achieve zero net emissions? The recent IPCC report explores that question by analyzing dozens of models (31 to be exact) that build on a variety of assumptions and technological possibilities to cover a wide range of possible futures. Those models are used to create hundreds of *business-as-usual* scenarios (scenarios that assume that no climate change policies are implemented), as well as mitigation scenarios associated with different targets for temperature or GHG concentrations.

The key finding from those scenarios and models is that carbon neutrality requires action on four fronts (Figure 1.3):

- Decarbonized electricity production
- Electrification (to increase reliance on that clean electricity), and where that is not possible, a switch to cleaner fuels

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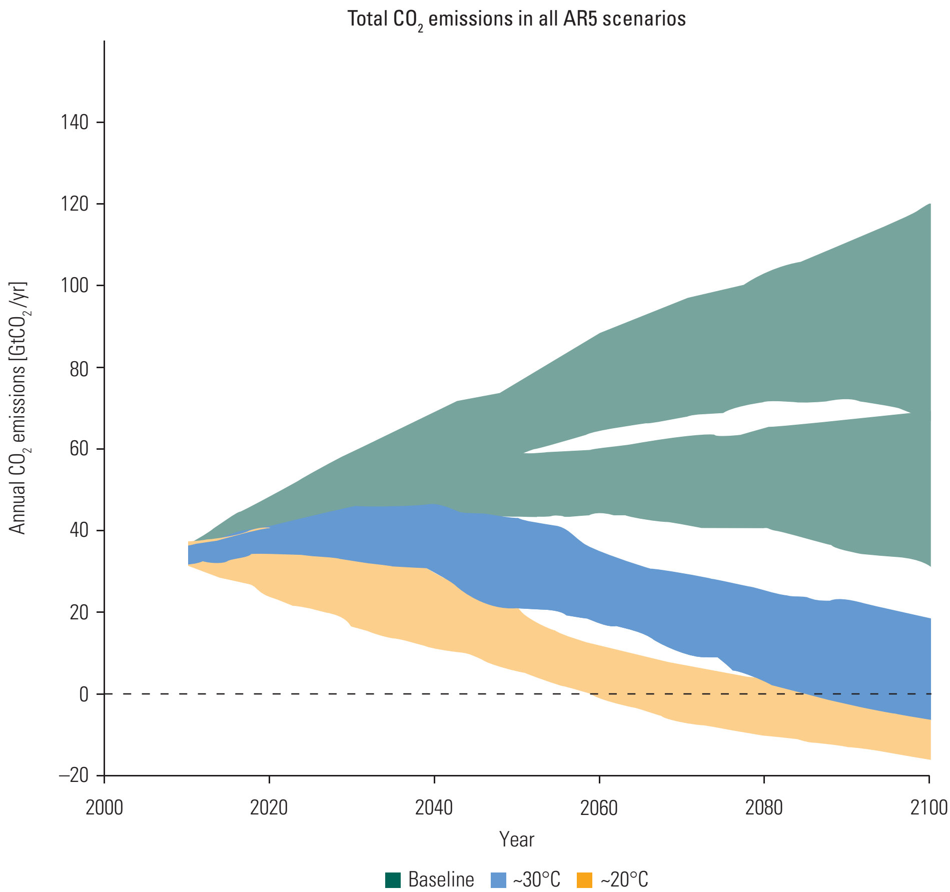
### FIGURE 1.2 Carbon Neutrality Is Needed by 2100 to Achieve Climate Goals



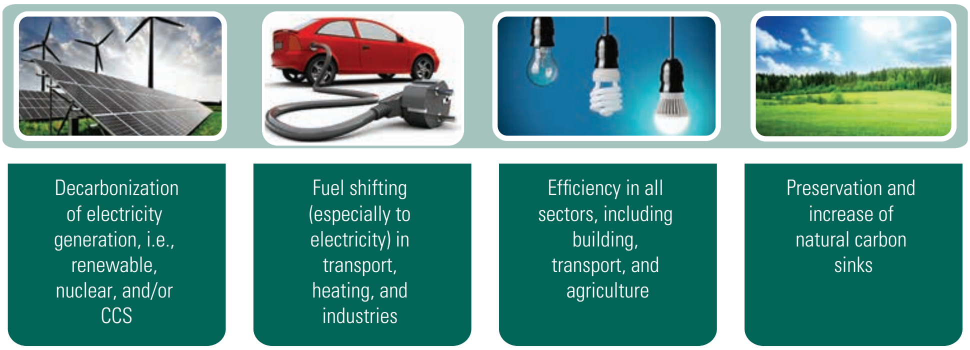

*Source:* Adapted from IPCC (2014).

- Improved efficiency and reduced waste in all sectors
- Preservation and increase of carbon sinks such as forests and other vegetation and soils

Those are the pillars of carbon neutrality inasmuch as they are required to achieve climate change stabilization in a cost-effective way, no matter the level at which one wants to achieve stabilization. That is an area of full consensus across all models, irrespective of the temperature target (Audoly, Vogt-Schilb, and Guivarch 2014; IDDRI/UNSDSN 2014; IEA 2014; Krey et al. 2014; Williams et al. 2012). Only the pace of progress depends on the temperature target.

Action in any of the four pillars can therefore be considered "robust" policy options if climate stabilization is to be achieved, in that they are needed no matter what is eventually revealed about the current uncertainties (about the exact

**FIGURE 1.3 The Four Pillars of Decarbonization**

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response of climate systems to more emissions and about policies and technology development). In 2050, assuming that the world is on the path to climate stabilization, the measures implemented in the four pillars cannot appear as mistakes—the worst that could happen is that a particular country may have implemented them *too quickly* or *too slowly*.

Organizing measures according to those pillars is also a useful way for policy makers to translate the economy-wide objective of zero net emissions into operational objectives underpinned by well-defined sector-specific policies, which can be more easily managed by separate institutions or ministries.

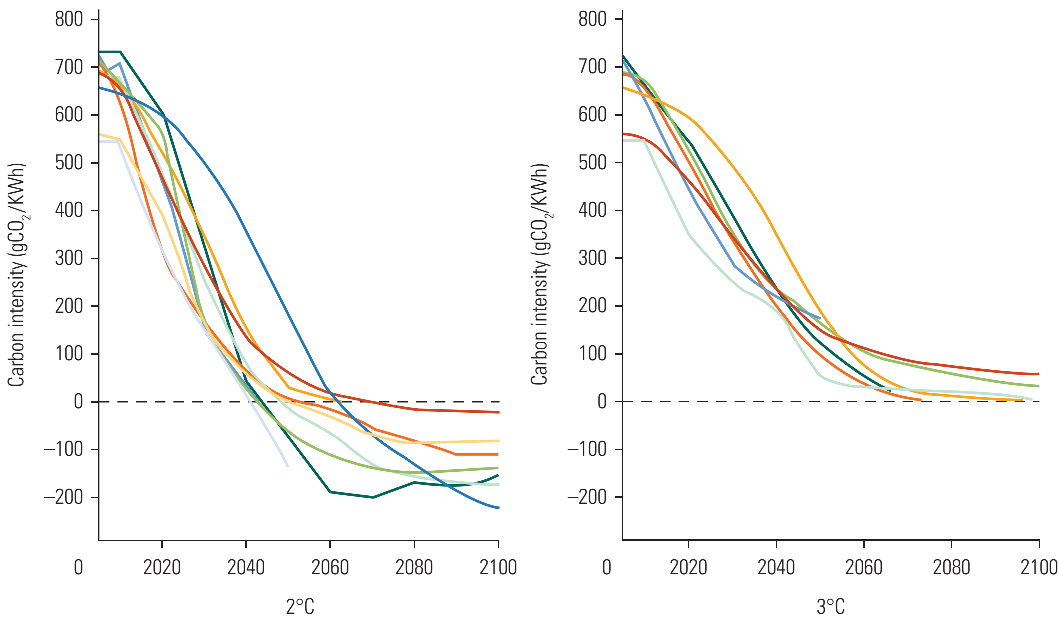
## Pillar One: Decarbonization of Electricity Production

To achieve zero net emissions requires full decarbonization of power generation. As Figure 1.4 shows, pathways consistent with a temperature change of around 2°C require the carbon intensity of global electricity production to decrease to near zero around 2050. That implies that high-income countries and emerging economies (such as China, India, and South Africa) would have to decarbonize electricity around midcentury and then rely on negative emissions. Low-income countries—which represent a small share of global electricity consumption—would have a few more decades, but they too would eventually need to converge to zero-emissions electricity eventually. If the target is 3°C, carbon neutrality could be delayed slightly to occur around 2080, and the need for negative emissions becomes much lower.

Reducing electricity-related emissions to zero implies a rapid penetration of carbon-free technologies, and even negative-emission technologies. As Figure 1.5 illustrates, for a 2°C target, the share of low-carbon or negative-carbon energy

**FIGURE 1.4 The Possible Paths to Decarbonizing Electricity**

*(Carbon content of global electricity in two scenarios: on the left-hand side, a stringent GHG concentration target [consistent with 2°C]; on the right-hand side, a less stringent GHG concentration target [consistent with 3°C])*



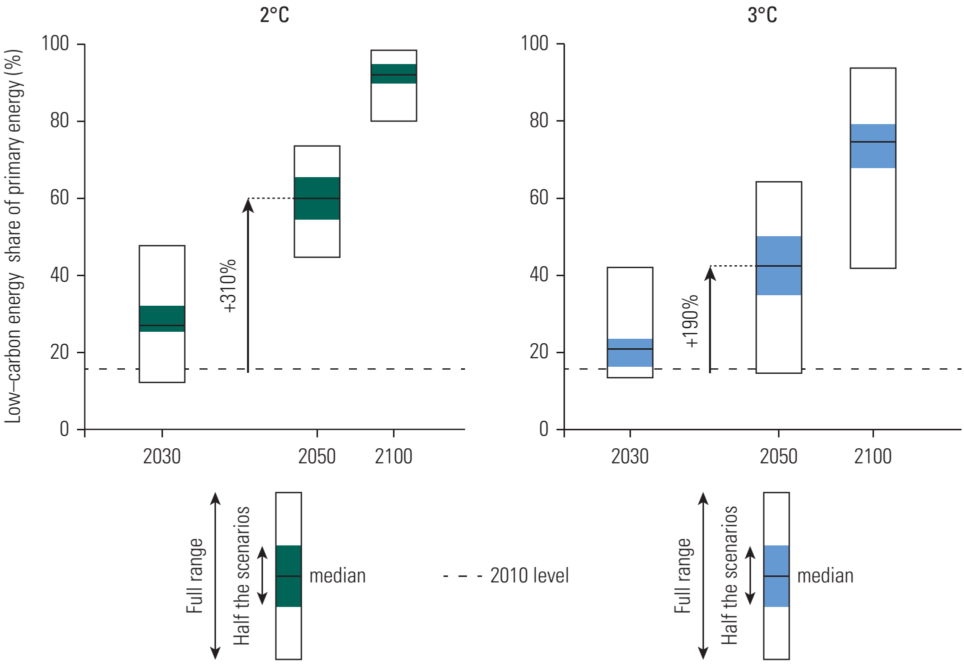

*Source:* Audoly, Vogt-Schilb, and Guivarch (2014) based on the AMPERE research project that integrated and compared multiple model results. The models used are a representative subset of those reviewed by the IPCC. Other analyses—such as the International Energy Agency's 2014 Energy Technology Perspective—find similar results.

*Note:* Each thin line corresponds to the pathway simulated by one integrated assessment model (the reported carbon intensity for 2005 and 2010 varies among models, because they use different scopes and sources of historical data for calibration).

supply—from renewable energy (such as wind, solar, and hydropower), bioenergy and bioenergy coupled with CCS, and nuclear power—must rise from less than 20 percent in 2010 to about 60 percent in 2050 (bioenergy with CCS produces negative emissions that offset emissions from the remaining 40 percent). That would be an increase of more than 300 percent in 40 years, and those technologies need to achieve the negative emissions that are needed to compensate for the positive emissions of the remaining fossil-fuel-based energy. For a 3ºC target, the required increase is still rapid, with the share increasing by 275 percent by 2050 to reach a penetration of about 42 percent.

Fortunately, some of those technologies, such as wind and solar power, have matured in the past decades and have seen their costs decrease rapidly—in fact, their costs are now approaching those of technologies that use fossil fuels. Other technologies, such as CCS, are still in the early stages of development and deployment, and their potential and economic viability are more uncertain.

**FIGURE 1.5 Low-Carbon Energy Sources Must Become Much More Widely Used**
*(Required scaling up of low-carbon share of primary energy for 2030, 2050, and 2100 compared with 2010 levels in mitigation scenarios leading to approximately 2°C and 3°C warming)*




*Source:* Adapted from IPCC (2014).

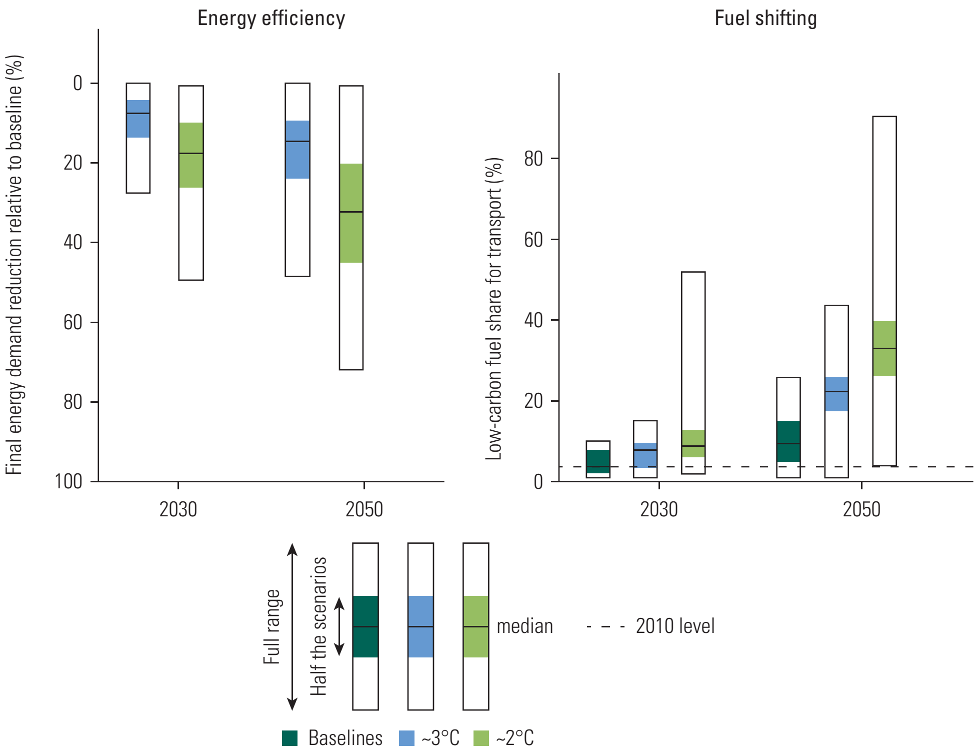
## Pillars Two and Three: Efficiency and Electrification or Fuel Shifting in All Sectors

All countries must reduce inputs of (carbon-intensive) energy and materials in production, largely through increased efficiency (to reduce overall energy demand) and by shifting to clean electricity or other low-carbon fuels. That action applies to all sectors, but especially to the energy-intensive sectors, like transport, building, and industry:

- In the *transport sector* (figure 1.6), pathways compatible with 2°C warming generally show a steady decrease in energy demand (by about 20 percent in 2030 and 30 percent in 2050), combined with an increase in the use of low-carbon fuel—mostly electricity thanks to electric cars and public transit—from a few percentage points today to more than 30 percent in 2050. The efforts for 3°C warming are less demanding but would still require significant changes in the same direction.
- In the *building sector* (figure 1.7), the initial emphasis should be placed more on energy efficiency than on fuel shifting (especially by 2030). That fact is consistent

**FIGURE 1.6 The Transport Sector Needs to Tackle Both Efficiency and Fuel Shifting**

*(Energy demand and share of low-carbon fuel in transportation sector, for baseline scenarios, and for scenarios that stabilize concentration at 2°C [i.e., concentrations of 430–530 ppm $CO_2$e] and at 3°C [i.e., concentrations of 530–650 ppm $CO_2$e])*




*Source:* Adapted from IPCC (2014).

*Note:* The left-hand side shows the reduction in final energy demand relative to the baseline, in percentages, in scenarios that keep warming below 2°C or 3°C; the right-hand panel shows the penetration of low-carbon fuels in the sector in these scenarios.

with technical studies that show that there is great potential for energy efficiency in buildings (especially in the residential sector), but that it will take a long time to capture it at reasonable costs. Also, a shift to electricity for heating is efficient only for highly energy-efficient buildings.

- In the *industry sector* (figure 1.8), it is harder to generalize given the large differences among the subsectors. Industries that produce GHG emissions by using energy should be able both to shift to electricity and to increase their energy efficiency. However, industries that produce GHG emissions directly from their industrial processes will have to either focus more on efficiency or totally shift to another process (such as using wood as a construction material instead of steel or cement).

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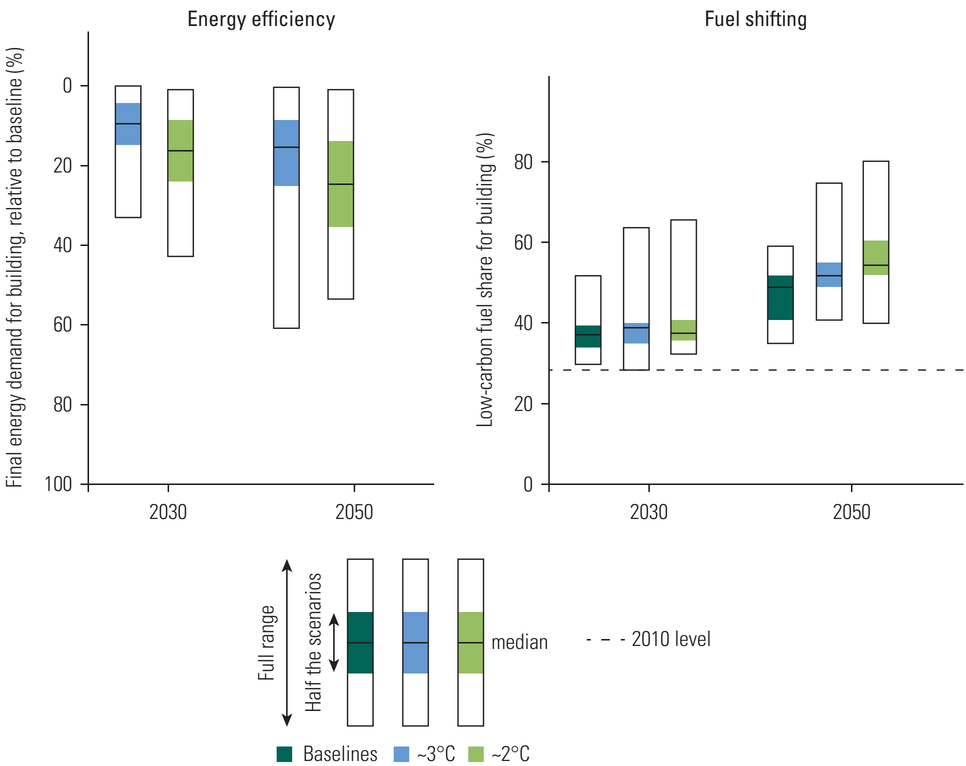
**FIGURE 1.7 The Building Sector Can Focus First on Efficiency**

*(Energy demand and share of low-carbon fuel in building sector, for baseline scenarios, and for scenarios that stabilize concentration at 2°C [i.e., concentrations of 430–530 ppm $CO_2e$] at and 3°C [i.e., concentrations of 530–650 ppm $CO_2e$])*



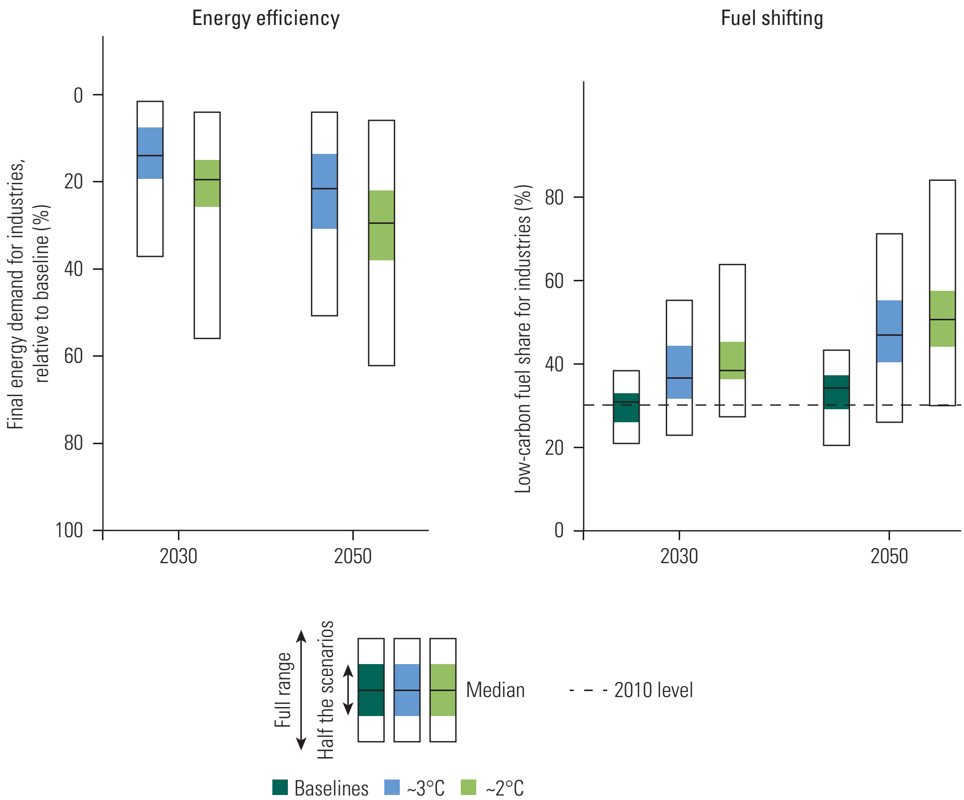

*Source:* Adapted from IPCC (2014).

*Note:* The left-hand panel shows the reduction in final energy demand relative to the baseline, in percentages, in scenarios that keep warming below 2°C or 3°C; the right-hand panel shows the penetration of low-carbon fuels in the sector in these scenarios.

As for agriculture and forestry, efficiency efforts include minimizing the loss and waste of food, reducing both direct energy use (for tractors and machinery) and indirect energy use (for the production of fertilizers). Efficiency in agriculture also means reducing emissions of non-$CO_2$ gases, such as nitrous oxide, from the use of fertilizers.

More specifically, measures can be taken to reduce the energy intensity of production (that is, energy needs per unit of land) and to increase productivity (that is, kilogram of commodity per unit of land). As long as the productivity increase is larger than the increase in emissions per land unit, sustainable intensification can bring mitigation benefits (Smith 2013). For instance, bringing global yields 50 percent closer to their potential for crops and 25 percent for livestock by 2050 could decrease agriculture and land-use emissions by 8 percent (Valin et al. 2013).

**FIGURE 1.8 The Industry Sector Doesn't Fall Neatly into Any One Approach**
*(Final energy demand and share of low-carbon fuel in industrial sector, for baseline scenarios, and for scenarios that stabilize concentration at 2°C [i.e., concentrations of 430–530 ppm $CO_2e$] and at 3°C [i.e., concentrations of 530–650 ppm $CO_2e$])*



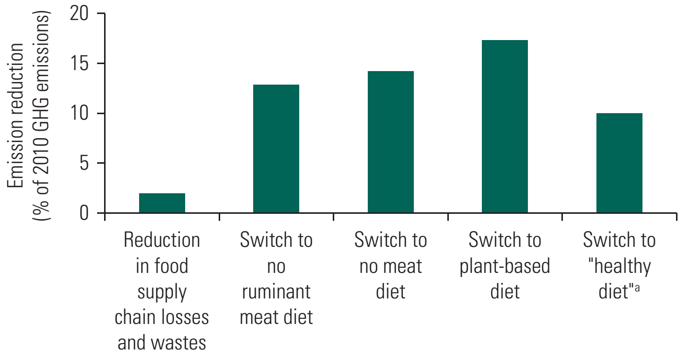

*Source:* Adapted from IPCC (2014).

*Note:* The left-hand panel shows the reduction in final energy demand relative to the baseline, in percentages, in scenarios that keep warming below 2°C or 3°C; the right-hand panel shows the penetration of low-carbon fuels in the sector in these scenarios.

Other ways to mitigate include minimizing the loss and waste of food, increasing the supply of less emission-intensive products (including biofuels and wood materials), and changing food demand to shift consumption toward low-carbon food products and to free land for other mitigation activities. For example, dietary changes have a considerable mitigation potential, with a switch to a plant-based diet potentially lowering GHG emissions by over 15 percent (figure 1.9).

With regard to fuel switching, the use of wood fuels and materials can further contribute to mitigation by replacing fossil fuels, along with substituting carbon-intensive construction materials. Yet harvest rates need to be sustainable so that the temporary releases of carbon from logging can be compensated through regrowth. Moreover,

**FIGURE 1.9 Changing the Way We Eat Can Help**
*(Food demand related mitigation potential in 2050)*




*Source:* Smith et al. (2013).

a. The "Healthy Diet" is based on Harvard Medical School's recommendations and implies a reduction of animal product intake in countries with rich diets and an increase in countries with poor or protein-deficient diets.

improving the use of traditional biomass, which is used by 2.7 billion, mostly poor, people to meet cooking energy needs through improved cookstoves could reduce emissions by up to 6 percent of the 2010 emission levels, in addition to the substantial health benefits that would bring (Smith et al. 2013); see a more in depth discussion in chapter 7).[2]

## Pillar Four: Preservation and Increase of Natural Carbon Sinks

All countries will need to improve the management of landscapes, including trees, other vegetation, and soils, to boost their ability to act as a net-carbon sink—indeed, models reviewed by the IPCC show that the agriculture, forestry, and other-land use sectors will likely need to achieve carbon neutrality by 2030, in addition to meeting an increasing demand for food and possibly bioenergy. Mitigation policies can reduce emissions from land management and land-use conversion and can increase the removal of carbon from the atmosphere.

Land use-based mitigation could be an important contributor to the global abatement needed by 2050 to maintain temperature change below 2°C (Smith and Bustamante 2014). As a step in that direction, the September 2014 New York Declaration on Forests aims for stopping natural forest loss by 2030, the restoration of 150 million hectares of degraded landscapes and forestlands by 2020, and a significant increase in the rate of global restoration thereafter, which could reduce emissions by 4.5–8.8 $GtCO_2$ per year by 2030.[3] Beyond 2030, in the scenarios in which CCS is not available or not deployed at scale, the negative emissions required to keep temperature change below 2°C or even 3°C have to be generated from the agriculture, forestry, and other land-use sectors, creating immense challenges in land-use management.

### Progress Is Needed in All Countries on All Four Pillars, but with Flexibility as to When, Where, and How

Stabilizing the climate by 2100 requires reducing *net* emissions of long-lived GHGs to zero. Thus, positive emissions somewhere can be offset by negative emissions elsewhere: through increased carbon sinks—for example, through reforestation or better soil management—or by combining bioenergy (renewable energy derived from biomass, such as wood, crops, or crop residues) with CCS.[4]

The flexibility that entails is critical to keep costs down and to allow countries to follow paths that are better adapted to their economic and political realities. Negative emissions provide three types of flexibility:

- *Temporal flexibility*. The possibility to achieve negative emissions after 2050 allows for lower efforts and higher emissions before 2050, without compromising temperature targets.
- *Spatial flexibility*. If some countries can achieve negative emissions, then it is possible to reduce net $CO_2$ emissions to zero even as other countries continue to emit.
- *Sectoral flexibility.* Given that reducing emissions to zero will be particularly difficult in some sectors such as air transport, negative emissions in the power sector would help countries achieve net zero emissions.

That flexibility reduces the overall cost of mitigation in scenarios with negative emissions. In particular, models estimate that the cost of reaching the 2ºC target more than doubles if CCS is not available (for technological, economical, or social acceptability reasons).[5] Countries can therefore proceed at different speeds across the four fronts, but significant progress is required on all four in all countries.

## Notes

1. As well as ocean acidification, sea level rise, and biodiversity losses (Steinacher, Joos, and Stocker 2013).
2. Improved cookstoves also have large co-benefits.
3. For more information on the New York Declaration, visit the United Nations website at http://www.un.org/climatechange/summit/wp-content/uploads/sites/2/2014/09/FORESTS-New-York-Declaration-on-Forests.pdf.
4. Energy models see the deployment of bioenergy in energy systems increasing over time, especially with stricter climate targets, which raises concerns as bioenergy competes for land with forests and other carbon sinks, and with food production. The hope is that new technologies will develop second- and third-generation biofuels that either use residues from agriculture or can be grown on degraded and arid lands.
5. This number may even be an underestimate, given that some models simply cannot reach the 2°C target if CCS is not available.

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# 2. Acting Sooner Rather than Later

- Early action avoids lock-ins and is cost-effective: delays today need to be offset by faster decarbonization tomorrow, meaning higher costs and stranded assets.
- Early action does not mean doing everything right away. Some actions are better delayed in low-income countries until technology costs have decreased, but all countries can identify early action that makes sense within their overall development strategy.
- Early action is prudent: it hedges against the risk of fast and expensive decarbonization imposed by external pressures, radical innovation, trade and consumption trends, or revisions in climate risk estimates.

The latest science tells us that the global community's goal must be zero net emissions of carbon dioxide ($CO_2$), preferably by 2100, and that whatever the exact temperature target, policy makers would do well to organize their actions around four pillars: (a) electricity decarbonization, (b) electrification and fuel shifting, (c) improved efficiency and reduced waste in all sectors, and (d) climate-friendly landscape management. But when should they start? And how fast should they go? Not surprisingly, significant uncertainties surround these questions, but there are also a number of solid results around which robust policy making can be designed—robust in the sense that it minimizes the risk of regrets of doing either too little or too much.

## *Feasible* Really Means Cost-Effective

Of course, timing would seem to hinge on the feasibility of various temperature targets (for example, 2°C or 3°C above preindustrial levels), but defining what is feasible has proved challenging. In theory, emissions can be reduced to zero overnight, if we shut down the global economy.[1] Thus, the feasibility question is not a technical question, but rather an economic, social, and political one (Guivarch and Hallegatte 2013). Moreover, since feasibility largely depends on economic costs and distributional impacts, it is a function not only of which target is selected but also of which policies are implemented to get there.

So given that we know that smart and efficient policies lower costs and make ambitious targets more feasible, another approach—which the latest Intergovernmental Panel on Climate Change (IPCC) report follows—is to look for cost-effective pathways that balance the short-run and long-run costs and risks. Encouragingly, the IPCC finds that multiple pathways (including various combinations of short-term and long-term actions) are compatible with various targets. However, pathways with fewer reductions over the short term require disproportionally larger efforts later on. In climate policies, as in everything else, procrastination has costs.

Take the case of the 2010 Cancún pledges, which were agreements to emission reductions by 2020, taken by countries at negotiations during the 2010 Conference of Parties of the United Nations Framework Convention on Climate Change in Cancún, Mexico. If implemented, they would allow for modest greenhouse gas (GHG) emission reductions between now and 2030.[2] After that (between 2030 and 2050), emissions would have to be cut by 6 percent per year (averaged across time and models) to reach the 2°C target. But doing so would be extremely costly and would require a dramatic and rapid transformation (Riahi et al. 2015). The fastest any country has ever managed to decarbonize outside of an economic collapse was 4.5 percent per year, which France achieved during its nuclear energy buildup (Guivarch and Hallegatte 2013). As another point of reference, the European Commission is committed to only a 1 percent decrease rate between 2008 and 2020, and about 3 percent per year between 2020 and 2030.

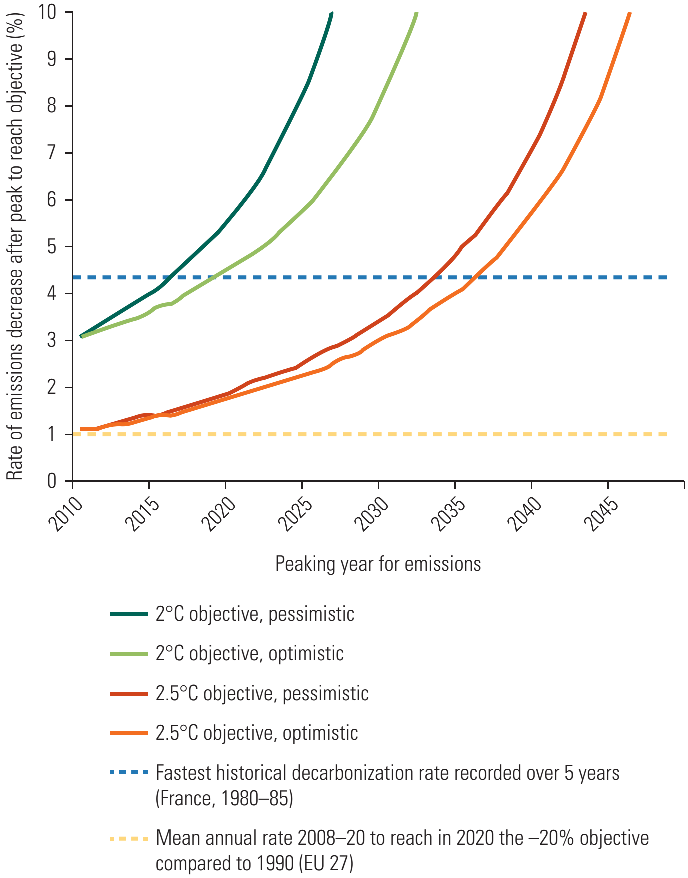
In cost-effective scenarios, by contrast, short-term emission reductions would be much larger—leading to annual emissions of fewer than 50 gigatons of carbon dioxide ($GtCO_2$) equivalent by 2030—thereby cutting in half the subsequent pace of emission reductions from 6 percent to 3 percent per year. Such a front-loaded scenario would enable countries to enjoy much lower economic costs, less stranding of assets (reflecting unanticipated or premature retirement of capital and equipment), and lower economic and technological risks from aggressive emission reductions (Riahi et al. 2015).

The difference in cost between immediate and delayed action is significant. If additional mitigation efforts are delayed until 2030 and the target remains unchanged, the IPCC scenarios show an average 50 percent increase in middle-term costs (in the 2030–50 period) and a 40 percent increase in long-term costs (in the 2050–2100 period).

How should countries decide to balance short-term versus long-term actions? One way is to focus on the peak date of global emissions—that is, the date at which global emissions start to decrease. In fact, the peak date has become a common indicator to measure the timing of efforts in developing countries with rapidly growing emissions—for example, in the recent U.S.-China pact on climate change, China committed to a peak date in 2030 or earlier.

Of course, the later the peak date, the higher the resulting temperature change or the larger the emission reductions that are needed after the peak year. Moreover, the rate of emission reduction that is required to reach various climate targets increases more than proportionally with the global peak date, so that delays in action have a strong impact on the efforts needed after the peak date (figure 2.1).[3] For instance, the required rate rises from less than 4 percent to between 5 percent and 8 percent when the peak date is delayed from 2015 to 2025. As figure 2.1 shows, 2020 is already late for

**FIGURE 2.1 Delaying the Peak Date Means Cutting Emissions even Faster Later**




*Source:* Adapted from Guivarch and Hallegatte (2013).

*Note:* The optimistic and pessimistic lines refer to different assumptions regarding how emissions will change before the peak date. The figure also reports the fastest historical decarbonization rate achieved over five years (removing periods of negative economic growth) and the European Union commitment between 2008 and 2020.

a peak date if the final objective is a 2°C warming. It would necessitate a reduction in emissions of 5–6 percent per year in the absence of negative emissions.

Further, if emission reductions are limited in the short run, maintaining the temperature increase below 2°C will require large negative emissions after 2050—necessitating the aggressive deployment of land-use policies that store carbon (like reforestation) and biofuels with carbon capture and sequestration (CCS). However, these technologies and measures have potential risks and adverse side effects (especially on biodiversity and food security)—particularly if they are deployed on a large scale—and their future availability is still debated. As a result, excessively modest efforts over the short run increase both long-run costs and risks—putting the target achievement at risk if required technologies are not available (or cannot be implemented for reasons linked to social acceptability or trade-off with other policy objectives).

## Cost-Effectiveness Requires Early Action

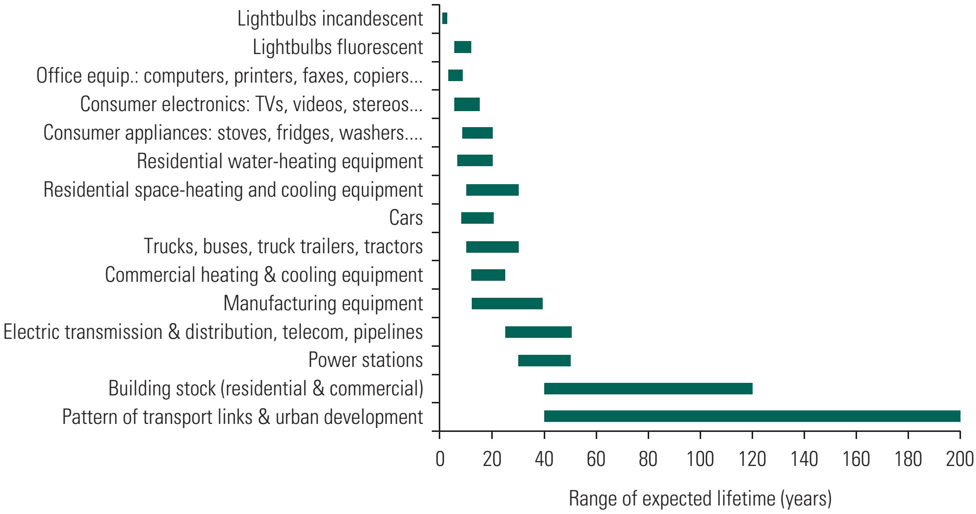
Early action is more cost-effective. Of course, it does not mean that all countries need to do everything at once. Delaying some measures can also save money: technologies improve over time and become more affordable, reducing abatement costs. But technologies improve only if they are invested in, so at least some countries have to start implementing the most promising technologies. The richer countries must lead in funding such frontier innovation and in creating the demand that allows for large-scale deployment and lower costs. The decrease in the cost of solar panels that occurred over the past decade was largely due to economies of scale and innovation linked to Germany's feed-in tariff. But although poorer countries may prefer to wait for the cost of some technologies to decrease before they support them, they can still identify early action that makes sense within their overall development strategy.

Indeed, one major reason early action is more cost-effective is that delayed action involves continued investments in emitting equipment (like coal power plants) that are not compatible with a target of 2°C or even 3°C —and thus entail large costs later on from the need to retire capital early to reach the climate goals. That is particularly the case in developing countries, where economic growth and urbanization imply that much infrastructure will be built in the next decades. In those countries, there is no such thing as "*waiting*"—investments will happen anyway. The choice is between current development trends (assuming environmental considerations can be brought in later on) or leap-frogging by building cleaner and more efficient infrastructure and equipment from the start.

The failure to act early means that large amounts of $CO_2$ emissions are "*committed*" far into the future, because they are embedded in installed capital (like existing power plants, transport systems, and industrial, residential, and commercial infrastructure that often have long lifetimes) (Davis, Caldeira, and Matthews 2010; Guivarch and Hallegatte 2011; Julie Rozenberg, Vogt-Schilb, and Hallegatte 2014). In fact, as figure 2.2 shows, the long lifetime of some components of existing capital—such as transport networks and urban development patterns, which can range from 40 to 200 years—means that emissions will continue over the next decades and even beyond, unless retrofitting is possible (such as adding CCS to a coal power plant or improving a building's energy efficiency).

Today's investment decisions add to committed carbon emissions. The fossil-fuel-burning plants built around the world in 2012 will emit approximately 19 billion $GtCO_2$ over their expected 40-year lifetimes—more than the 14 billion tons of $CO_2$ emitted annually by all fossil-fuel power plants operating in 2012 (Davis and Socolow 2014). And the decisions that are being made now in the fast-growing cities of the developing world are creating committed emissions through their long-lived impact on energy demand (Avner, Rentschler, and Hallegatte 2014; Guivarch and Hallegatte 2011). For example, whether or not a public transit system exists may well determine

**FIGURE 2.2 Long-Lived Capital Lasts a Very Long Time**
*(Expected lifetime of different types of assets)*




*Source:* Philibert (2007).

how a city develops with regard to housing density, hence, the efficiency of carbon prices (see box 2.1).

The concept of committed emissions also applies to fossil-fuel exploration. At this point, the size of the world's known oil reserves are growing faster than the rate of extraction (Matthews 2014). Yet we already know that 60–80 percent of current reserves of fossil fuels cannot be fully used in any scenario consistent with a 2°C or a 3°C warming (figure 2.3). Carbon capture and sequestration would make it possible to use more coal, but the global potential of CCS remains very uncertain.

So what can be done to turn this situation around? The only way to reduce committed $CO_2$ emissions is to replace some of the installed capital with new, lower-emitting installations (or in the case of fossil-fuel reserves, keep them in the ground). But doing so rapidly would imply retiring capital and equipment before the end of their planned lifetimes—in effect, turning them into "*stranded assets*," which could create significant costs for the owners of the assets and the workers who depend on them (Johnson et al. 2015; Lecuyer and Vogt-Schilb 2014; Julie Rozenberg, Vogt-Schilb, and Hallegatte 2014).[4]

Yet not acting quickly would make the situation worse. As a recent study finds, strong action in the short term (maintaining GHG emissions at low levels, around 50 $GtCO_2$ equivalent, in 2030) would require stranding some assets between now and 2030 (about 150 gigawatts [GW] of coal generation), but it would make it possible to reduce emissions between 2030 and 2050 without additional stranding (figure 2.4). Instead, weak action (unchanged climate policies that would result in emissions

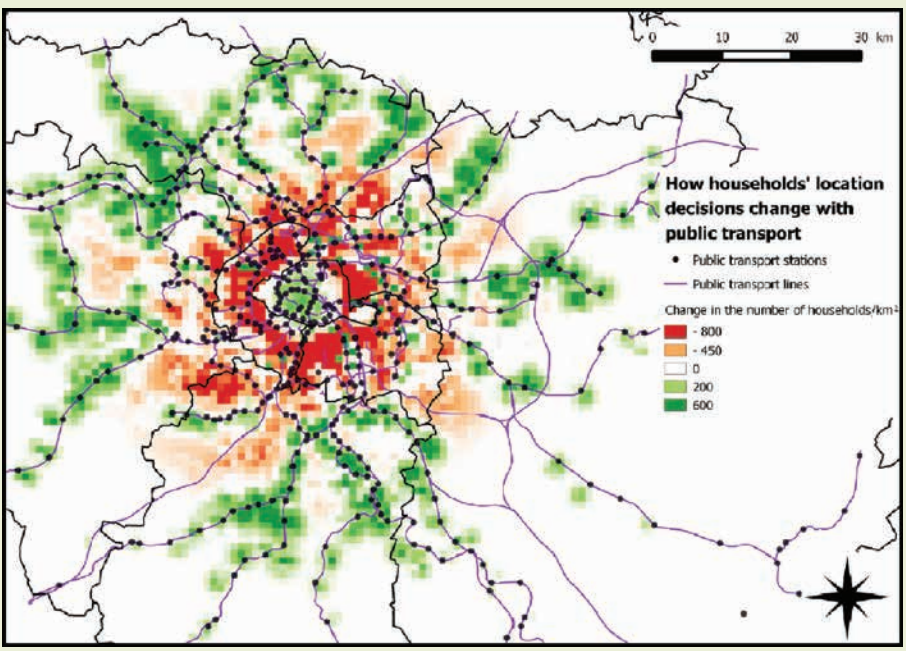
## BOX 2.1 An Extreme Case of Commitment—Urban Forms

Many cities in developing countries are in the process of designing and building their infrastructure network—thus shaping their urban form for the next century and beyond (Lecocq and Shalizi 2014). It is therefore critical to understand how those short-term decisions will affect how those cities could implement—or be affected by—a carbon price in the future and how effective that price would be in cutting emissions. To investigate this issue, Avner, Rentschler, and Hallegatte (2014) compare two cities: Paris as it existed in 2010 and an imaginary Paris in which no public transport infrastructure would have ever been built. They use a transport–land-use model calibrated for those two scenarios to compare the resulting carbon dioxide ($CO_2$) emissions and their response to carbon pricing or other gasoline taxes.

Figure B2.1.1 shows the spatial differences in population densities and location choices between the two visions of Paris (without and with public transport infrastructure):

- Without public transport, households have an incentive to locate relatively close to the city center to shorten their commutes, but they do not concentrate around transport infrastructure (shown by the red and orange shaded areas that appear within the first 15 kilometers of the city center).

**FIGURE B2.1.1 Viewing Paris through a Public Transport Lens**
*(Comparison of households' location decisions when public transport exists relative to a counterfactual scenario without public transport)*




*Source:* Avner, Rentschler, and Hallegatte 2014).

(*Box continues on the following page.*)

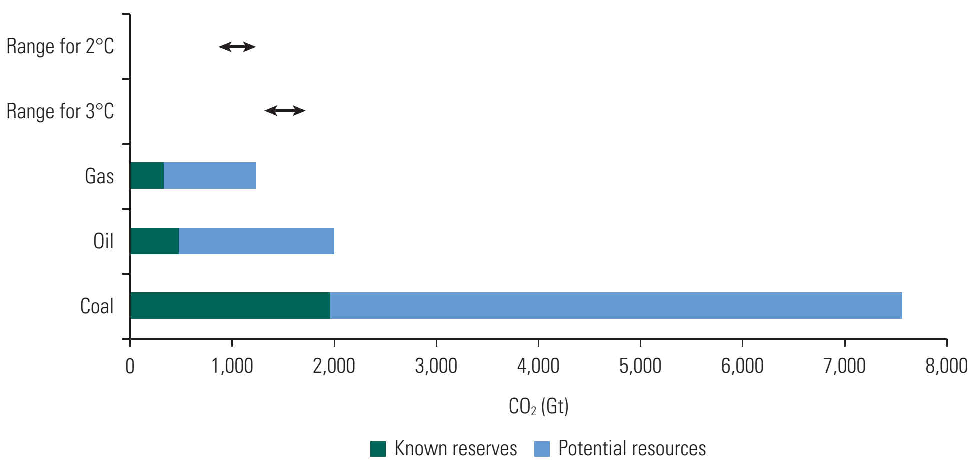
**BOX 2.1 An Extreme Case of Commitment—Urban Forms (continued)**

- With public transport, households are able to move farther away from the city center (thanks to a loosening of the commuting constraint) but only along the public transport lines (to benefit from quick and cheap access to central Paris). That is evident in the green shaded areas, which show that when public transport exists, the population redeploys toward the outskirts of the urban area, but in a denser way that follows the public transport infrastructure. This *"transit-oriented development"* increases the modal share of and accessibility to public transit.

The urban forms generated in the presence—or absence—of public transport infrastructure are almost irreversible. The inertia in urban form goes beyond the lifetime of buildings and infrastructure. Since cities go through a process of permanent and largely uncoordinated reconstruction of individual buildings or segments of infrastructure, urban forms are extremely difficult to change, even when large social gains are possible. That inertia is illustrated by the benefits from large-scale reconstruction after disasters that remove some of this irreversibility, as occurred with the Great Fire of Boston in 1872 (Hornbeck and Keniston 2014).

These urban forms, in turn, affect greenhouse gas emissions and the effectiveness and efficiency of various instruments to reduce emissions. Thus, the future ability of fast-growing cities in the developing world to curb their transport emissions—and to reduce pollution and remain competitive in the face of possibly high carbon prices—is highly dependent on their near-term choices in infrastructure investments.

**FIGURE 2.3 A Majority of Known Fossil-Fuel Reserves Will Need to Stay in the Ground**




*Source:* Adapted from Clarke et al. (2014) and McGlade and Ekins (2014).

*Note:* In green and orange are the ranges of $CO_2$ emissions compatible with 2°C and 3°C, respectively. The darker shading depicting oil, gas, and coal represents known reserves (what is recoverable under existing economic and operating conditions); the lighter shading represents resources that are theoretically feasible. The coal numbers include hard coal and lignite.

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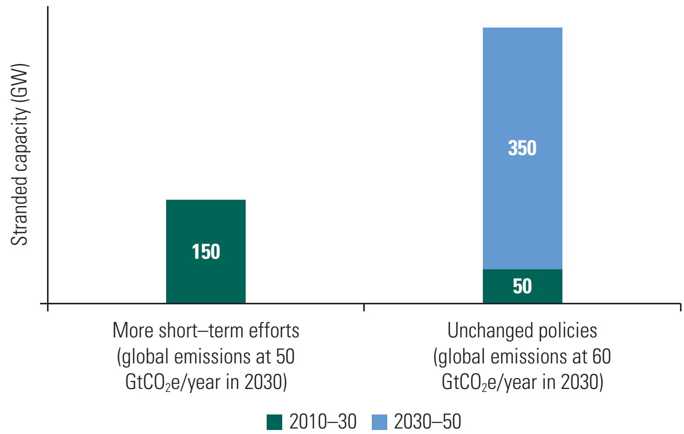
**FIGURE 2.4 Early Action Results in Fewer "Stranded Assets"**

*(Mean stranded capacity of global conventional coal power plants from 2011 to 2050)*




*Source:* Adapted from Johnson et al. (2015).

*Note:* The 2011 to 2050 period is divided into two periods (2010–30 and 2030–50), depending on the ambition of mitigation policies in the 2010–30 period.

reaching more than 60 $GtCO_2$ equivalent by 2030) would strand fewer assets by 2030 (50 GW) but then necessitate stranding of up to 350 GW between 2030 and 2050.

Countries differ as to the age or vintage of their energy infrastructure, and thus as to when it needs to be replaced (Davis and Socolow 2014). Countries that will be building a large share of energy infrastructure in the near future have a high risk of creating stranded assets. As such, they may want to take advantage of the natural turnover of capital to improve the environmental performance of installed capital without having to retire it early.

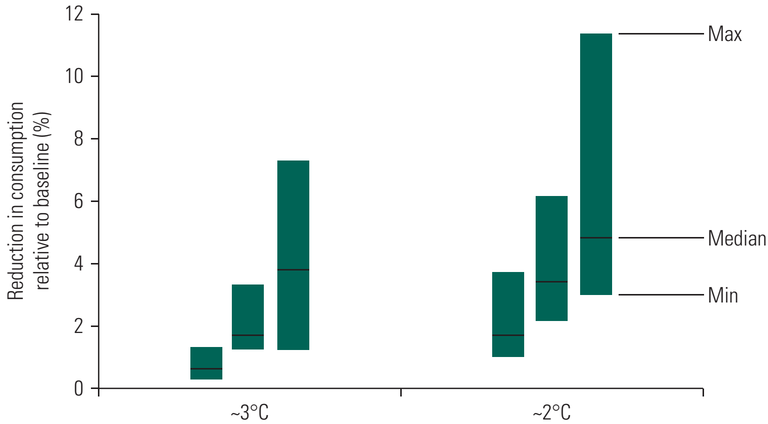
## The Costs of Early Action Should Be Modest

How much will early action cost? The IPCC provides an estimate of global mitigation costs for various climate objectives (expressed here in foregone consumption compared with a baseline world with neither climate impacts nor mitigation policies). As figure 2.5 shows, for the 2°C target, overall world consumption is estimated to be lower by about 2 percent in 2030 and about 4.5 percent in 2100 compared with the no-climate-concerns baseline (meaning with neither policies nor impacts).

These are global numbers, and even as they are modest overall, they can represent a heavy burden for individual countries and regions. The cost-minimizing pathways examined by the IPCC assume that mitigation happens wherever and whenever it is cheapest. The result is that a large share of the mitigation would happen in developing countries. For a 2°C target, the IPCC finds that local mitigation (expressed as a percentage of local consumption) is lower than average in the

**FIGURE 2.5 Mitigation Costs Rise with More Ambitious Target, but with a Big Uncertainty Range**

*(Reduction in aggregate world consumption—a measure of the economic cost of mitigation relative to a baseline of no climate change or climate policy, in 2030, 2050, and 2100, for two climate objectives—2°C and 3°C)*



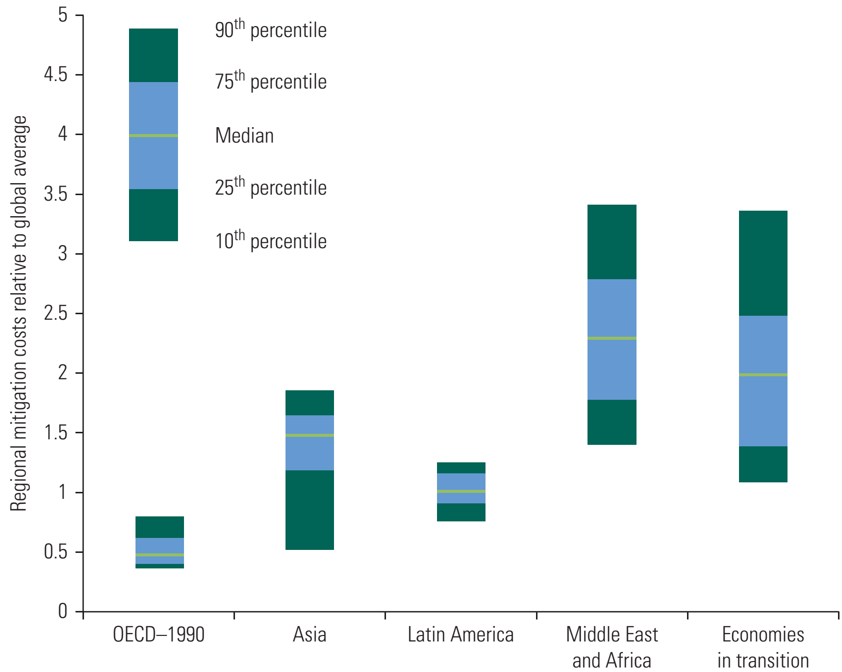

*Source:* Adapted from IPCC (2014).

*Note:* The reduction in consumption is based on a comparison with a world with no climate change, so includes neither impacts nor policy costs.

member countries of the Organisation for Economic Co-operation and Development (OECD), close to the average in Latin America, and larger than average in other developing countries (Asia, the Middle East, and Africa) and in economies in transition (figure 2.6). Results are very similar for higher-temperature targets.[5] Note that these are the costs of abatement taking place in each region, not the costs paid by each region, as these two costs can be disconnected—for instance, with richer countries paying for part of the abatement happening in developing countries through carbon markets or financial transfers.

These cost estimates are extremely uncertain. As figure 2.5 shows, the 4.5 percent reduction associated with a 2°C target is actually the median of a 2–6 percent range. This uncertainty reflects the inherent limitations of models, as well as the differences across them—for instance, regarding their representation of structural change and the dynamics of labor markets. It also arises from the fact that a great deal will depend on the available technologies and the efficiency of the policies that are implemented. For instance, reaching the 2°C target without CCS—because the technologies cannot be developed or scaled up—would be around 140 percent more expensive than with this technology. Other technologies are less critical: phasing out nuclear energy or limiting the scaling up of solar or wind energy would increase costs by less than 10 percent. Finally, models usually assume that least-cost policies are implemented, and they optimally distribute abatement efforts across sectors and fuels. This approach is in contrast with existing climate policies, which are often partial in their sectoral coverage.

**FIGURE 2.6 The Costs of Mitigation to Reach the 2°C Target Varies across Regions**



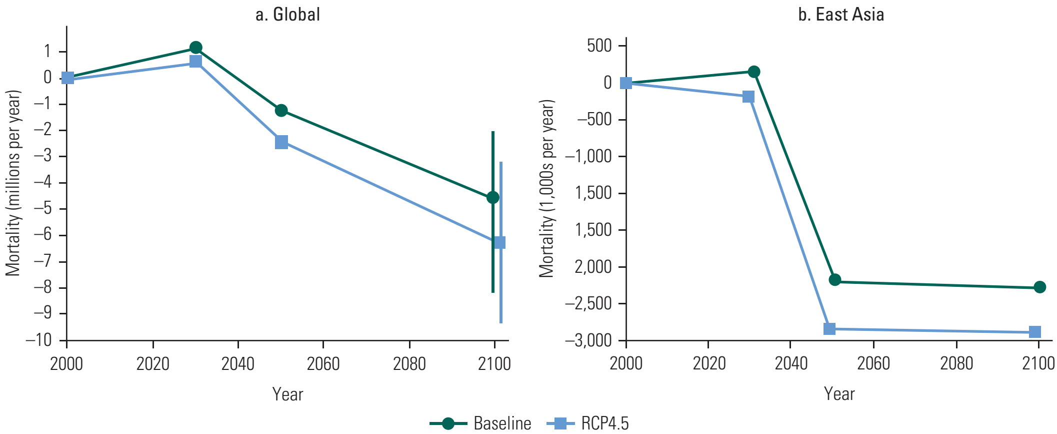

*Source:* Adapted from IPCC (2014).

*Note:* Regional mitigation costs are relative to the global average, assuming a uniform least-cost global climate policy, in the absence of any transfers. These costs are the costs of abatement *taking place* in each region, not the costs *paid* by each region, as these two costs can be disconnected—for instance, richer countries can pay for part of the abatement happening in developing countries through carbon markets or financial transfers.

In addition, these costs are not net costs. They do not capture the benefits from lower climate change impacts, which are the final objective of climate policies. Nor do they capture the many co-benefits of climate action. Recent studies find that health benefits from lower air pollution alone would exceed the cost of mitigation in many regions, at least until 2030 (Shindell et al. 2012; Thompson et al. 2014). A pathway leading to a reduction in $CO_2$ concentrations from 720 to 525 parts per million in 2100 would avoid 0.5 million premature deaths annually in 2030, 1.3 million in 2050, and 2.2 million in 2100 (West et al. 2013). Those health co-benefits can be particularly large in places where air pollution has reached alarming levels in the past decade (Matus et al. 2012). For example, in East Asia, about 500,000 premature deaths would be avoided annually in 2050 under climate mitigation (figure 2.7, panel b).[6]

Many other co-benefits are likely to occur in various sectors (World Bank 2014). Reduced air pollution also increases agricultural yields, and better public transit reduces congestion and traffic accidents—all of which would generate large economic benefits.[7] Climate-friendly landscape management can be more productive and more resilient to climate shocks. A lower dependence on imported energy for fossil-fuel

**FIGURE 2.7 Lower Air Pollution Means Lower Mortality Rates**
*(Changes in mortality in baseline and mitigation scenarios, from particles [PM2.5] at the global scale and in East Asia)*




*Source:* Adapted from West et al. (2013).

*Note:* REF is a reference scenario leading to a $CO_2$ concentration of about 720 ppm in 2100. RCP4.5 is a scenario with mitigation policies that would lead to 525 ppm in 2100. (More ambitious decarbonization would tend to increase co-benefits). In panel a, uncertainty bars show the uncertainty that arises from the concentration-response function (not all uncertainties).

importers would boost energy security.[8] And in periods of economic recession with large idle resources, macroeconomic benefits are possible if green investments create an economic stimulus.[9]

Focusing on the investment side, the IPCC estimates that reaching the 2°C target would require additional investments of about $400 billion per year. Similarly, New Climate Economy's report (NCE 2014) finds an additional investment need of around $300 billion, compared with baseline investment needs of $5.5 billion per year.[10] This additional cost (a 5 percent increase) is not negligible, but it does not change qualitatively the challenge of mobilizing the financial resources needed for development.

The relative modesty of additional investment needed for climate mitigation is explained by the fact that increased costs in some sectors (like renewables) are partially compensated by savings in other sectors (figure 2.8). For instance, investment needs in the extraction of fossil fuels or in power plants without CCS are substantially reduced in scenarios with high energy efficiency and lower GHG emissions, keeping additional investment needs at manageable levels compared with overall infrastructure needs.

Finally, the higher up-front costs of greener technologies and options are often compensated—at least partly—by lower operational costs. For instance, that is the case for more efficient buildings that reduce heating or air-conditioning costs, and for renewable power like solar or hydro that do not require purchasing fuel.

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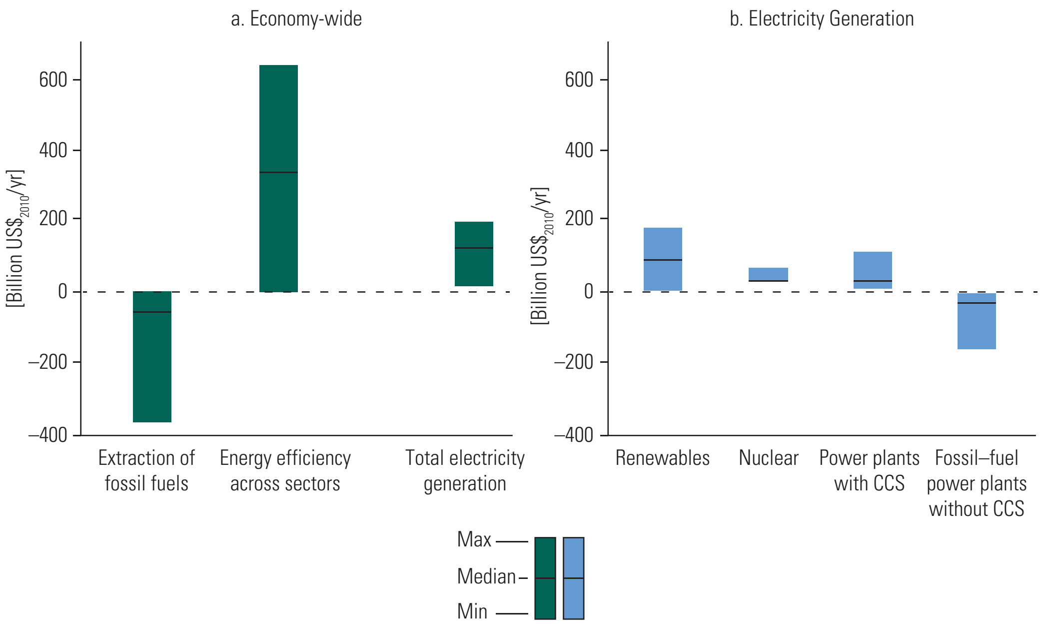
**FIGURE 2.8 Early Action Investments Kept Manageable by Lower Needs in Some Sectors**




*Source:* Adapted from IPCC (2014).

*Note:* Change in annual investment flows are relative to the average baseline level over the next two decades [2010–29] for mitigation scenarios consistent with a 2°C pathway [concentrations of 430–530 ppm $CO_2e$ by 2100. The figure on the left shows changes in investment flows economy-wide. The figure on the right shows the breakdown within electricity generation, which is broken into four components with the four light-blue bars: renewables, nuclear, power plants with carbon capture and storage (CCS), and fossil-fuel power plants without CCS.

Overall then—and keeping in mind the caveat about how uncertain they are—costs appear relatively modest. But the question of financing the needed investments could still be a binding constraint. That is a particular concern for the many developing countries in which the burden could be concentrated. It is critical therefore to ensure financial flows that help dissociate *who pays* from *who acts* so that the abatement realized in poor countries need not be the cost they have to bear. Instruments that disconnect the location of abatement from its financing include market instruments—such as international or networked carbon markets—and direct financial flows. These issues of financing are discussed in depth in chapter 6.

## Early Action Paths Are Prudent

We often think of mitigation and emission reduction as a way to hedge against climate change risks that are uncertain but potentially "severe, widespread, and irreversible" (using language from the IPCC [2014]). But the reality is that even without taking climate impacts into account, countries that delay action and develop in a carbon-intensive way could be exposed to higher costs when (and if) they decide to act later.

Thus, even countries that do not believe in the validity of a 2°C goal or that do not concur with the final decarbonization objective may want to diversify away from excessive carbon dependency and start transitioning toward lower carbon as a strategy to hedge against the costs of delayed mitigation—particularly if such short-term efforts could bring some local and immediate benefits (like reduced pollution, increased export earnings, or reduced congestion).

After all, external trends may even render carbon-intensive assets prematurely obsolete ("*stranded*") and thus trigger an "*imposed*" decarbonization. Such trends include green technology developments, market demand and price shifts, local demands for cleaner air, changing consumer' preferences toward greener products and lifestyles, and policy efforts to mitigate climate change in major export markets. They can also include direct external pressure from the international community to increase participation in climate change mitigation efforts—whether through border tax adjustments or diplomatic pressures in other domains (like trade agreements).

Since transitions are smoother when chosen and managed, countries may want to opt for low-carbon policies to prepare for a world that is moving toward greener technology, rather than risk being forced to act precipitously in the future. For carbon-intensive countries, investing in energy efficiency and renewable energy is comparable to diversifying an asset portfolio to manage risk. Investors need not think that an event will occur to hedge against it—nonzero probability that an event may occur implies that there is an economic benefit from diversification and hedging. Countries with high carbon intensity may see a value in diversifying their economy and reducing their emissions, if they believe there is a nonzero probability that a carbon-intensive economy will be hurt by future socioeconomic trends (including climate policies in other countries, especially trade partners).

## Notes

1. The dynamics of the carbon cycle makes things more complicated: past emissions and resulting warming have already affected the ability of ecosystems and oceans to capture $CO_2$ from the atmosphere, so it is not possible to return to preindustrial carbon flows instantaneously.
2. The 2020 pledges made by countries at the Cancún Conference of the Parties would actually allow for emissions of 55 gigatons of $CO_2$ to 65 gigatons of $CO_2$ equivalent per year in 2030, slightly higher than the 2010 level (about 50 $GtCO_2$ equivalent) and a modest reduction compared with *business as usual*.
3. In addition, that nonlinearity still exists if bounded negative emissions are possible, even though the possibility of negative emissions reduces the level of effort needed after the peak.
4. As Rozenberg, Vogt-Schilb, and Hallegatte (2014) discuss, stranding assets can be a perfectly rational decision from an economic perspective, and it is not always better to avoid stranded assets. However, stranded assets still represent a loss that early action can mitigate.
5. Even though costs per unit of emission reduction are often lower in developing countries, their total costs are likely to be higher for multiple reasons, including the rapid expected growth in baseline emissions in the absence of climate policy, their current fossil-fuel-based energy mix,

and higher energy and carbon intensity. Also countries and regions that are heavily dependent on carbon-intensive industries or on fossil-fuel extraction would of course be affected more negatively than the others (for example, in the Middle East), whereas other countries could benefit from reduced energy imports or bioenergy exports.

6. There is an active debate regarding how to measure co-benefits, to ensure in particular that co-benefits are not included when they could be captured easily and cheaply by nonclimate-related measures. For instance, health co-benefits from better air quality could at least be partly generated by measures that are not linked to climate mitigation, sometimes at a lower cost.
7. Most economic analyses suggest that the *carbon externality* (that is, the impact through climate change) of driving is small compared with other externalities, such as traffic accidents, congestion, and local air pollution (Bento et al. 2013; Parry, Heine, and Lis 2014).
8. Estimates regarding future oil prices are very uncertain, but climate policies hedge against that uncertainty (J. Rozenberg et al. 2010).
9. This question generated a debate, especially in Europe after the 2008 crisis. See, for instance, (Brahmbhatt 2014; World Bank 2012; Zenghelis 2014).
10. Other estimates differ, sometimes markedly (Kennedy and Corfee-Morlot 2013; McKinsey 2013; World Bank 2012), but they all agree that the additional cost of low-carbon development is small compared with infrastructure financing needs in the baseline scenario.

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# 3. Plan Ahead with an Eye on the End Goal

- Climate mitigation strategies should focus on measures that carry co-benefits and provide synergies with economic development.
- They should also favor measures with high emission-reduction potential—even if those measures are slow to implement and are not the less expensive ones available in the short term.
- To be effective, the long-term goal of carbon neutrality should be translated into operational short-term objectives at the sector level.

So far in this report, we have stressed the need for a long-term goal of bringing net carbon emissions to zero by 2100 to stabilize climate change at a reasonable temperature level. We have explained how carbon neutrality can be achieved by acting on four fronts: (a) electricity decarbonization, (b) electrification and fuel shifting, (c) efficiency in end-use sectors, and (d) preservation and increase of carbon sinks. And we have documented the rationale for early action, especially regarding long-term investments.

The next step is to determine emission-reduction pathways that can achieve those goals at the sector level. The key question here is how to determine the right set of measures at each point in time given the uncertainty, disagreement, and multiple objectives that complicate development policy making. This chapter explores a core principle to navigate this complexity—namely, to prioritize what is urgent and what carries local and immediate co-benefits. The focus on urgency comes from the fact that end goals constrain short-term choices and should drive today's priorities. The emphasis on co-benefits comes from the fact that the goal is low-carbon development—not mitigation for mitigation's sake. The chapter also reviews some of the tools that can be mobilized to design operational strategies at the sector level.

## Factor in Uncertainty, Disagreement, and Multiple Objectives[1]

As policy makers focus on how to design climate change policies, they find themselves running into a wall of sorts—the reality that a *deep uncertainty* surrounds so many key issues. Although the long-term objective is clear, the best measures to reach it are still being heatedly debated.

By deep uncertainty, we mean what happens when the parties to a decision do not know or cannot agree on (a) the models that relate the key forces that shape the future, (b) the probability distributions of key variables and parameters in those models, or (c) the value of alternative outcomes (Lempert et al. 2003).[2] For example, the likelihood of experiencing a car crash is easily estimated from ample historical data. But the likelihood of experiencing a given long-term land-use pattern or level of global economic growth is neither reliable nor verifiable, making it difficult to agree on the most likely scenario.

In the case of climate change, there are several types of uncertainties. First, we know that increased emissions lead to a changing climate, but how exactly local climates will be affected is highly uncertain. In some parts of the world, such as West Africa, models even disagree as to whether the climate will become drier or wetter. Second, we know a changing climate will have many negative consequences. But even in the most studied sector (agriculture) and in places with the best data availability (developed countries), the uncertainty on the exact impact of a changing climate on yields and carbon cycles is great (Porter et al. 2014). In other sectors—such as ecosystem services or extreme events—the uncertainty is even greater.

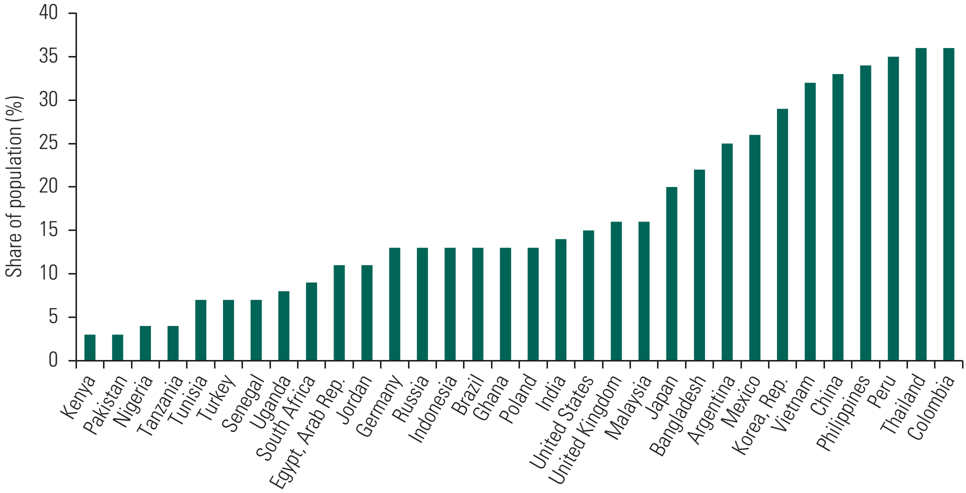
Third, we also know that policies and technologies can reduce emissions. But as countries make commitments whether action at the required level will follow is uncertain. Plus the availability and acceptability of technologies (such as nuclear or carbon capture and sequestration [CCS]) are uncertain. Most of the Intergovernmental Panel on Climate Change's scenarios that achieve a temperature rise below 2°C assume negative emissions in the second half of the century (Clarke et al. 2014). But if technologies to remove carbon dioxide ($CO_2$) from the atmosphere are not available, even greater efforts will be needed from other sectors.[3]

Compounding matters is the fact that those risks and uncertainties are perceived and valued differently across individuals, populations, and countries. For example, more than 30 percent of the population of the China, Colombia, Peru, the Philippines, Thailand, and Vietnam cite pollution and the environment as the *greatest threat in the world*, compared with less than 5 percent in Kenya, Nigeria, Pakistan, and Tanzania (table 1.). Also, some individuals may value economic development highly, whereas others prize their cultural and environmental heritage. Some may prioritize avoiding biodiversity losses, whereas others may not. Some may focus on worst-case scenarios, whereas others focus on more likely scenarios. And some individuals may worry more than others about the welfare of future generations.

Against this backdrop, how can policy makers design climate policies in an inclusive way, accounting for multiple viewpoints, and in an iterative risk management framework—one that accounts for uncertainty and can be revised as more information becomes available?

**FIGURE 3.1 Some Countries Worry Much More about Environmental Issues than Others**

*(Share of the population citing "pollution and the environment" as the "greatest threat in the world")*




*Source:* Pew Research 2014 Global Attitudes survey.

First, climate policies should generally aim to avoid making irreversible decisions and getting locked into patterns or technologies that would be difficult and costly to reverse if new information or changing preferences arise (Ambrosi et al. 2003; Lempert and Schlesinger 2000; Pizer 1999). For instance, it is almost impossible to transform a low-density city into a high-density city, even over the long term (chapter 2).

Second, climate policies should be robust, in that they should perform well under a broad range of possible futures, rather than just being optimal for the most likely future. For instance, a climate policy can be designed using projections of future costs of a green technology and turn out to be extremely efficient—provided that costs decrease as planned. But it could also totally fail if costs remain higher than expected. Alternative policies may not be as efficient in the considered scenario of rapid technological progress, but they may be more robust to less optimistic technology scenarios.

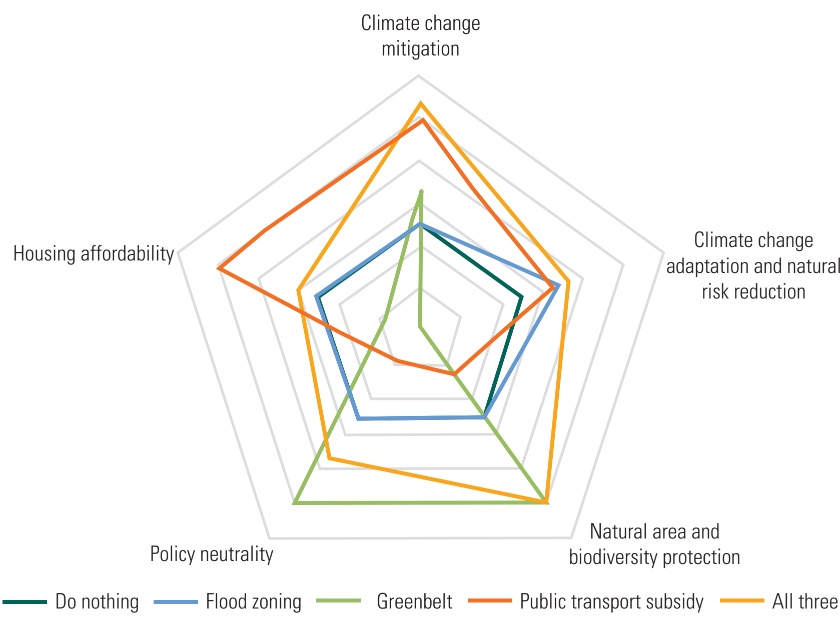
Third, climate policies need to combine multiple policy goals and create consensus. Take the case of a local decision maker faced with the following multiple objectives: (a) housing affordability, (b) climate change adaptation and mitigation, (c) the protection of natural areas and the reduction of sprawl, and (d) policy neutrality (no income redistribution). The policy options might include a greenbelt policy, a public transport subsidy, and a zoning policy to reduce the risk of flooding.

An analysis of that situation shows that each policy would contribute to some objectives but would hurt others (figure 3.2). However, a package can be designed that, for the same total cost, results in a net improvement for all the objectives. It may not be the preferred option for any individual, but all should agree that the package is better than the status quo. Such a package—depicted as the green line in figure 3.2—would include a greenbelt policy (in which the construction of new buildings is restricted), flood zoning, and a subsidy for public transit. It might have a greater chance of being implemented because it is more in line with the priorities of a larger share of the population (Viguié and Hallegatte 2012).

## Focus on What Is Urgent and Carries Co-Benefits

Of course, optimal solutions will differ across countries with varying degrees of resources, institutional capacity, transparency, accountability, and civil society capacity. Thus, decarbonization strategies need to be tailored to a country's circumstances, and

**FIGURE 3.2 Evaluating a Policy Package along Several Dimensions**
*(Consequences of a greenbelt policy, a public transport subsidy, and a zoning policy along five metrics that represent five policy objectives, compared with the do-nothing scenario)*




*Source:* Viguie and Hallegatte (2012).

*Note:* Points toward the outer edge of the spider chart represent better outcomes, whereas a move toward the inside is associated with worse outcomes. Preferred outcomes are (a) shorter average distances traveled by car, (b) fewer people living in flood-prone areas, (c) a smaller total urbanized area, (d) larger average dwelling sizes, and (e) neighborhoods with less income inequality.

*best practices* should be imported with caution. With that in mind, the *Inclusive Green Growth* report (World Bank 2012) proposes a core principle for selecting mitigation projects: maximize local and immediate benefits and avoid lock-in. Project selection can be done using two metrics (table 3.1):

- *Synergies.* Whether mitigation options provide net local and immediate co-benefits on top of long-term emissions reductions (such as energy cost savings and local air pollution reduction) or imply a trade-off with existing development goals (universal access to electricity could be threatened by higher costs from renewable energy).
- *Urgency.* Whether mitigation options are associated with high economic inertia (such as a risk of costly lock-in, irreversibility, or higher costs if action is delayed). If yes, then action is urgent; if not, it can be postponed.

For both metrics, the local context is key. In the case of synergies, growing concerns over local air quality in cities in China and India suggest focusing first on measures with large air pollution co-benefits. Where electrification or switching to cleaner cookstoves is a pressing development goal, that should be taken into account (Pachauri et al. 2013). In the case of urgency, not every developing country wants to be promoting innovation with pilot projects for CCS or large wind power plants. In some countries the priority will be to protect forests, whereas in others with rapid urbanization, urban planning and public transit should come first.

Synergies and trade-offs are often measured as the cost of using low-carbon options relative to a "*baseline*" alternative. Some will be more expensive by nature: retrofitting

**TABLE 3.1 Some Guiding Principles for Establishing Green Growth Strategies**

| | | Synergies | |
|---|---|---|---|
| | | **Low or negative (trade-offs)**<br>(to be considered at higher level of income or paid for by external funds) | **Positive**<br>(attractive regardless of income, provided that financial mechanism can be found) |
| Urgency | **Low:** less inertia and irreversibility risk | – Higher-cost renewable power threatening universal access to electricity<br>– Higher-cost fossil-fuel energy threatening switch from traditional biomass to healthier gas for cookstoves<br>– Reforestation/afforestation of degraded landscapes | – Lower-carbon, lower-cost energy supply (e.g., hydro)<br>– Loss reduction in electricity distribution<br>– Loss reduction in food supply chain<br>– Energy demand management (e.g., in building) |
| | **High:** greater inertia and irreversibility risk | – Reduced deforestation<br>– Increase investment in energy and transport R&D<br>– Pilot project with expensive technologies (CCS, concentrated solar) | – Land-use planning<br>– Public urban transport and transit-oriented development |

*Source:* World Bank (2012).

*Note:* CCS = carbon capture and sequestration; R&D = research and development.

a coal power plant with CCS requires investing in heavy material to capture, transport, store, and monitor carbon dioxide. Capturing $CO_2$ also reduces the yield of power plants, meaning that more coal should be burned to produce the same quantity of electricity. But a number of low-carbon options can pay for themselves or, better, can reduce emissions at a net economic benefit. LEDs are more expensive than incandescent lightbulbs, but energy savings over their lifetime mean that LEDs can be profitable even without a price on carbon, and they reduce emissions.

The fact that a low-carbon option brings net economic benefits does not mean that people will adopt it spontaneously. Market or governance failures may stand in the way. An option to improve energy efficiency can be unattractive to firms if investment is taxed while energy is subsidized. And homeowners will think twice before investing in thermal insulation for their houses if finding a qualified firm to install it is difficult, if they cannot easily verify the quality of the insulation they bought, or if energy bills are paid by tenants anyway (Allcott and Greenstone 2012; Giraudet and Houde 2013).

Some of the net benefit options will be beneficial for everybody in the long run, but they are not attractive to individual investors in the short term. The benefits of renewable power and energy-efficient cars will eventually pay for the cost of developing and deploying the technology, but knowledge spillovers mean that no investor will make the first move without help. Finally, many options are desirable as they bring social co-benefits to the community, such as reduced pollution, reduced congestion, or better agricultural yields (see chapter 2), but they suffer from the tragedy of the commons. Chapters 4 to 6 offer more insights on implementation barriers and how to overcome them.

More generally, measuring the *true* cost of an option is not without challenge. Different measures may interact with each other, something that the individual cost of each measure cannot reflect. For instance, emission reductions from using electric cars—and thus the cost of using electric cars to reduce emissions—depend on the carbon content of power generation, which in turn depends on other policy decisions (on policy interactions, see also chapter 8).

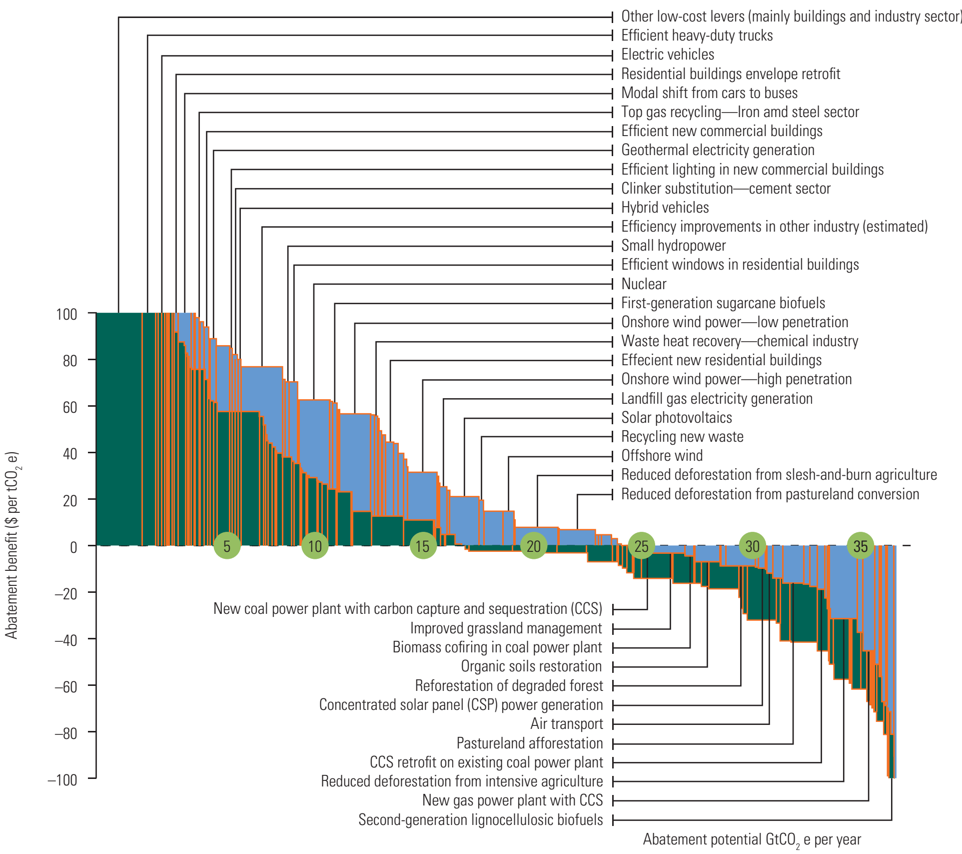
It is also difficult to summarize multiple objectives into a single cost metric: the cost of emission reductions can be small if measured in monetary terms, but it can be significant in nonmonetary terms. For instance, aggressive expansion of bioenergy may create risks for food security or may affect biodiversity in ways that are difficult to measure in financial terms. That is also true of the co-benefits from climate policies: the health benefits from better air are difficult to measure (consensually) in monetary terms. As a result, noneconomic costs and co-benefits are often simply left out of the analysis, creating a bias in the economic analysis of emission-reduction options.

One of the most common ways to illustrate the costs of different emission-reduction options is through marginal abatement cost (MAC) curves (ESMAP 2012; Kesicki and Ekins 2012; Kolstad and Urama 2014; NCE 2014). MAC curves offer a graphic representation of the results of model-based scenarios, showing information on abatement potentials and costs (or benefits) for a set of technical mitigation measures at a given date (for example, 2030). They rank the measures according to their economic costs, from the ones that come with net benefits to the measures that come with positive costs and trade-offs with income and growth (figure 3.3). And they are powerful communication tools—in particular, helping convey that large amounts of emission reductions are technically possible, and much of them will bring net economic benefits.

However, the very simplicity of these curves implies two important limitations. First, MAC curves may give the erroneous impression that a given amount of emission reductions can be enforced with the corresponding carbon price in the curve.[4] In most

**FIGURE 3.3 Marginal Abatement Cost Curves Provide Information on the Cost and Potential of Emission-Reduction Options**

*(A global marginal abatement cost curve, ranking options from those that bring the most co-benefits to the most expensive ones)*




*Source:* NCE (2014).

*Note:* Each bar represents an emission-reduction option, showing how much it could reduce emissions (abatement potential) on the horizontal axis; and the benefit or cost of doing so (in dollars per tons of $CO_2$ reduced) on the vertical axis. Options above the zero line generate net benefits; those below come with net costs. Green bars include only reduced operating costs as benefits, whereas blue bars include other co-benefits, such as reduced health impacts.

cases, that is not the case: enforcing a given measure requires tackling a number of government and market failures, as discussed in parts II and III of this report.[5] Second, MAC curves do not convey information on the time dimension—that is, how long it would take to implement a measure and thus the relative urgency of that measure. As a result, they are often misinterpreted as a kind of *dispatch* function that calls for doing the cheapest options first (Vogt-Schilb and Hallegatte 2014). For instance, the MAC curve displayed in figure 3.3 may give the false impression that action on deforestation or the development of CCS should be delayed until after other cheaper potentials have been captured, which, as it turns out, would be misguided.

So in addition to the cost dimension, planning short-term action requires accounting for the time dimension, in other words, the urgency of implementing each measure. Some measures with high abatement potential—such as switching to renewable power, retrofitting existing energy-inefficient buildings, or developing CCS—may take decades to implement, as a number of factors limit the speed at which some changes can occur. Among them are the following:

- *Slow capital turnover.* The average lifetime for energy-consuming equipment ranges from an estimated 7 years (for lightbulbs) to more than 35 years (Williams et al. 2014). Thermal electricity–generating plants have an average life expectancy of 30 years, although in practice most are used longer.[6] This is particularly important for coal-fired power plants, as some 40 percent of them are now less than 15 years old (Davis and Socolow 2014).
- *Slow technological diffusion.* Diffusing new technologies such as electric vehicles or heat pumps may take decades because of technical and sociological factors—including research and development time, lack of information, network effects, slow capital turnover, and learning-by-doing (Iyer et al. 2015). Typical time lags between the research and development of new technologies and first commercialization range from 5 to 10 years (Mansfield 1998). And lag times can take an average of 14 additional years from first commercialization to sales takeoff (Agarwal and Bayus 2002). Technologies that are components of interlocking networks, as in the case of electric or plug-in vehicles and specific charging infrastructure, exhibit the longest diffusion time scales (Grübler Nakićenović, and Victor 1999).
- *Availability of skilled workers.* Some mitigation options require new skills for workers—such as construction sector workers specialized in insulation—and building the skill base can take a long time, depending on the strength of lifelong (continuing) education (Jagger, Foxon, and Gouldson 2012).
- *Financial constraints.* Transitioning to a decarbonized economy will require significant up-front investment in clean capital. But as discussed in chapter 6, investors and firms frequently face capital rationing, many countries face severe fiscal constraints, and laws often limit the amount of debt that public agencies can contract—effectively restricting how much they can invest each year.

- *Institutional constraints and social norms.* Existing laws and regulations can make it difficult for investors to start new projects or invent new products (for example, regulations protecting historical sites in France have been an obstacle to the expansion of solar power). Some solutions require changes in the way institutions function, the creation of new institutions, or even changes in what is considered socially acceptable behavior and what is not (Weber and Johnson 2011).

The limited speed at which different options can deliver emission reductions is crucial information that needs to be available to decision makers when they are devising a strategy. Moreover, investigating the constraint on implementation speed is a way of identifying policies and measures that could accelerate the scale-up of some mitigation solutions.

Because of those limits, what is done now cannot be decided independently of the final objective. The optimal *quantity* of short-term abatement depends on long-term objectives (see chapter 2; Luderer et al. 2013; and Riahi et al. 2015). Moreover, ambitious long-term goals require focusing on the *quality* of abatement—that is, their potential long-term contribution to carbon neutrality. Emission-reduction options involving marginal changes in the economic system, at low cost but with limited potential for deep decarbonization, will not contribute to reaching the end goal and can be considered *low-quality* abatement (Vogt-Schilb, Hallegatte, and de Gouvello 2014).

Thus, short-term targets need to be reached with *high-quality* measures, which may be slow to implement and more expensive, but which will make deeper decarbonization possible in the long term. For example, the best strategy to decarbonize the European electricity sector is not to sequentially switch from coal to gas, and then from gas to renewable power. Rather, investing early in renewable power can smooth costs over time and avoid wasteful over-investment in gas power plants (Delarue et al. 2011; Lecuyer and Vogt-Schilb 2014).

Another reason not to focus only on the options with the lower technical cost in the short term is that many of the technologies used to reduce emissions (such as electric cars or renewable energy) are still in the early stages of their development. Since their costs will decrease as their deployment continues—through learning-by-doing effects or economies of scale—it makes sense to use some of these options in the short term to bring their costs down (Azar and Sandén 2011; Bramoullé and Olson 2005; del Río González 2008; Gerlagh, Kverndokk, and Rosendahl 2009; Kalkuhl, Edenhofer, and Lessmann 2012; Rosendahl 2004).

The need to keep long-term objectives in mind while designing short-term strategies is well illustrated by a recent study of Brazil's low-carbon development options. Another illustration is how differently Germany's energy transition strategy can be viewed depending on one's time frame (box 3.1).

So how can we easily communicate the time dimension (the urgency) along with the abatement cost (the synergies or trade-offs)? To communicate the time dimension, analysts often construct what has become known as a *wedge* curve (Pacala and Socolow 2004),

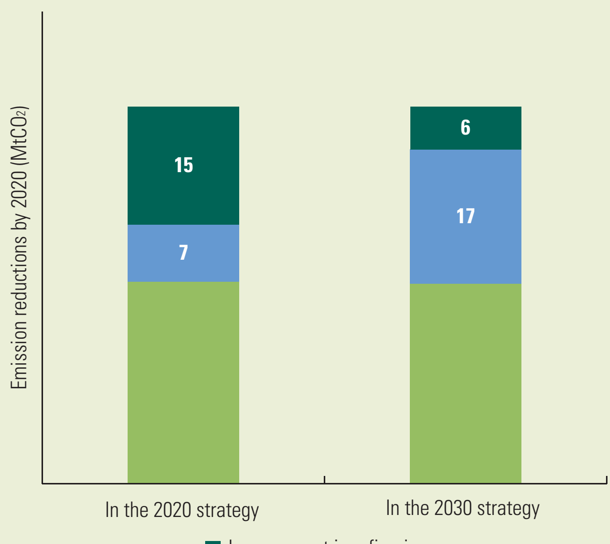
## BOX 3.1 Short-Term Strategies Need to Be Designed Keeping the Long-Term Goal in Mind—Examples from Brazil and Germany

### Picking a Path to Low Carbon in Brazil

As Brazil develops a low-carbon development strategy, it will have to choose whether and how much to invest in cleaner transportation (such as subways, trains, and waterways) and in upgrading existing refineries. An interesting question is whether the time frame should matter—that is, should policy makers look just 10 years ahead or further into the future. To study this question, we used a marginal abatement cost curve built at the World Bank for studying low-carbon development in Brazil in the 2010–30 period (Vogt-Schilb, Hallegatte, and de Gouvello 2014). Given that that is as far as the data extend, we opted to make 2030 our *long term* and to use existing data to design an optimal plan for 2020 (our *short term*). We then studied whether actions in the 2010–20 period are different if the 2030 goal is accounted for (figure B3.1.1).

The answer is yes. If the strategy for 2010–20 is designed to fulfil the 2020 target as an end goal rather than as a step toward the 2030 goal, it will achieve the same amount of emission reduction, but underinvest in high-potential options (such as clean transportation infrastructure) and overinvest in cheap but low-potential options (such as heat integration and other improvements in existing refineries). In other words, developing clean transportation infrastructure in the short term is appealing only if the long-term abatement target is accounted for.

**FIGURE B3.1.1 Using a Longer Time Frame Changes the Preferred Investment Plan**




*Source:* Adapted from Vogt-Schilb, Hallegatte, and de Gouvello (2014).

*Note:* The bars on the left represent the optimal emission-reduction strategy if the 2020 target is the end goal; the bars on the right are the optimal emission-reduction strategy by 2020, knowing the goal is to reduce emissions even further by 2030. For the same quantity of reduction, the latter uses more high-potential measures and fewer cheaper but lower-potential measures.

We also find that not developing clean transportation infrastructure in the short term (by 2020) precludes deeper emission reductions in the middle (2030) and longer term. Loosely speaking, the 2020-only strategy provides a sensible *quantity* of abatement by 2020, but that abatement is of insufficient *quality* to reach the subsequent 2030 target. Thus, if the goal is simply a 10 percent reduction in 2020, limited use should be made of subway and rail; however, those become critical to ensure the feasibility of a 20 percent emissions reduction by 2030.

**Germany's Energy Transition Deserves a Long-Term Perspective**

Germany has adopted an ambitious energy strategy. This *Energiewende* (or energy transition) combines a nuclear phaseout by 2022 with ambitious objectives for energy efficiency, and a goal of reaching an 80 percent share of renewable power generation by 2050. But it is being criticized for two main reasons: the large investments in renewables are costly, resulting in significant rises in electricity prices, and the nuclear phaseout implies a growing reliance on highly emitting coal over the short term.

The outcome of this debate will ultimately depend on whether and how the transition from coal to renewables will happen. The obvious risk is that current investments in the coal sector could lock Germany in a carbon-intensive development pathway. But if coal plants are decommissioned on time—a political economy challenge—and the 80 percent renewable target is met, then the short-term increase in coal-related emissions will, in retrospect, appear as a negligible bump in global emissions. The important outcome will be the development and scale-up of renewable energy technology that would bring Germany closer to the goal of zero net emissions from electricity generation.

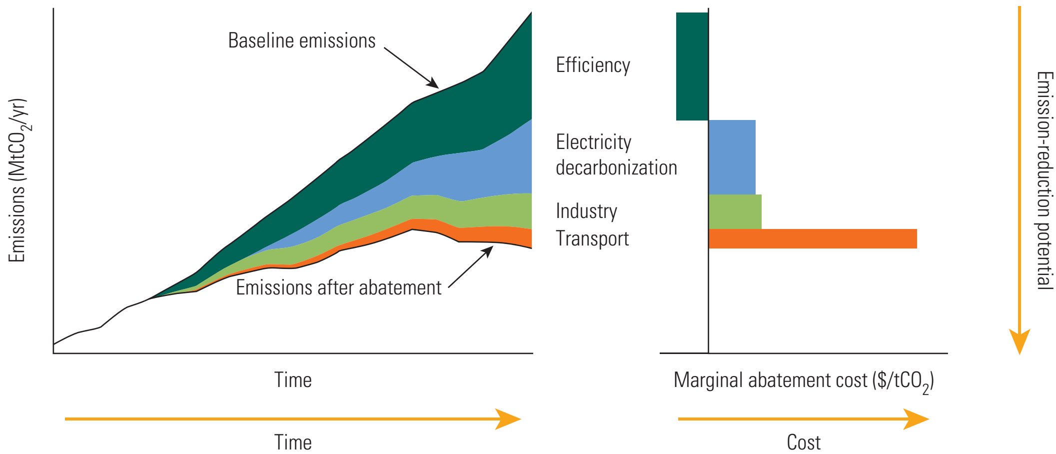
Moreover, this strategy creates global knowledge spillovers that will test and demonstrate technologies for scaling up renewable power and thus will help the rest of the world make their electricity generation carbon free. So looking at the end point and at the global scale, the short-term cost—slightly higher emissions in a country that accounts for less than 0.5 percent of world emissions—seems low compared with the long-term global benefits that would accrue if the transition is successful.

which shows the sequencing and deployment of various emission-reduction options (see left panel of figure 3.4).

MAC and wedge curves are both good ways of displaying complex information in a simple and informative way, but each covers only two out of the three key dimensions of emission-reduction options (time, cost, and potential). The good news is that they can be combined by *flipping* the MAC curve and then connecting it to a wedge curve. The resulting figure, shown in figure 3.4 with illustrative numbers, displays when early efforts are needed to reduce emissions, even in sectors that are more expensive to decarbonize. In figure 3.4, the transportation sector should start earlier than the decarbonization of electricity generation, in spite of its higher cost. The World Bank has recently developed a piece of software, MACTool, to help countries develop their own wedge and MAC curves (see box 3.2).

Another element that can be brought into the debate is the spatial dimension—that is, where within a country mitigation actions should take place. That aspect would be useful for policy makers who are wondering how to design a deforestation strategy, as explored for Brazil in box 3.3.

**FIGURE 3.4 Devising a Strategy Requires Information on Time, Cost, and Mitigation Potential**




*Source:* Author elaboration.

*Note:* By displaying the wedge curve next to the flipped MAC curve, this figure illustrates the need for sectoral abatement pathways to inform short-term action. In this illustrative example, avoiding carbon lock-in requires early efforts to decarbonize the transportation sector—even though the transportation sector is also the most expensive one.

## BOX 3.2 A World Bank Software for Comparing Abatement Options: MACTool

The World Bank has developed the Marginal Abatement Cost Tool (MACTool) to help governments compare the costs and benefits of emission-reduction options that can be used to build low-carbon scenarios at a national or subnational level.

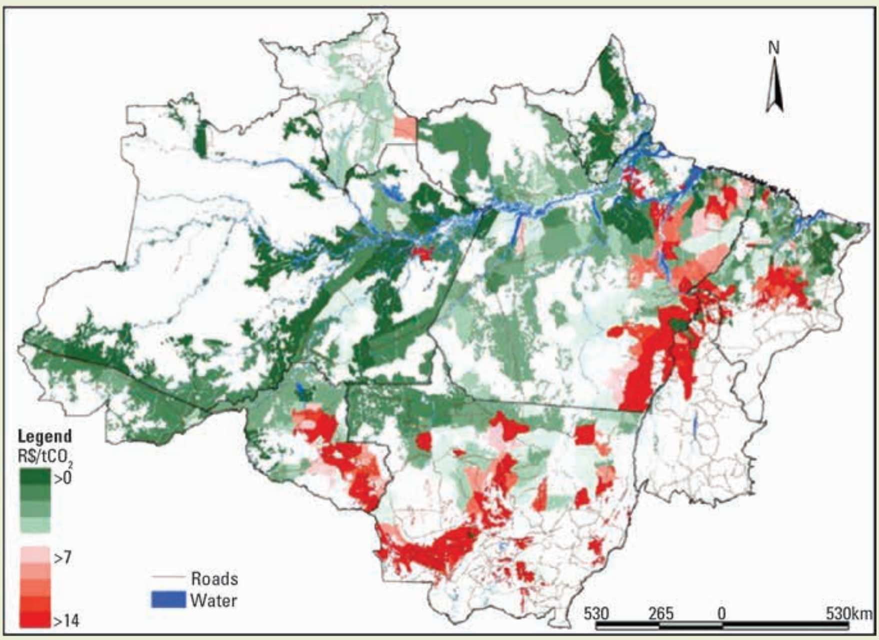
As inputs, MACTool uses the key sociotechnical parameters of a set of large mitigation measures and macroeconomic variables. For instance, technology options to produce electricity are characterized by the required capital and operation expenditures, as well as by their lifetime, energy efficiency, and type of fuel used. Physical constants, such as the carbon intensity of each fuel, are factored in. The user must also specify at least one scenario on the future macroeconomic variables of interest, such as the price of fossil fuels and the future demand for electricity. And the user must provide scenarios of future penetration of (low-carbon) technologies and measures, in both a baseline and at least one emission-reduction pathway (ESMAP 2012).

As outputs, MACTool computes the amount of greenhouse gases saved by each measure during the past year (in tons of carbon dioxide per year), as well as the cost of doing so (in dollars per ton of carbon dioxide)—illustrated with two figures: a MAC curve and an abatement *wedge curve*, which shows when each option would be deployed and how the different mitigation interventions add up over time (figure 3.4). It also estimates the incentives needed to make those options attractive for the private sector by calculating a break-even carbon price, and it helps governments assess the total investment needed to shift toward low carbon growth.

## BOX 3.3 Using *Space* to Design Deforestation Policies

Besides time, cost, and abatement potential, another dimension that matters is space. Not only is the set of feasible mitigation options dependent on the location, but so are the costs and benefits of those options. Take the case of a strategy to combat deforestation for Brazil (figure B3.3.1). The opportunity cost of land that is protected from deforestation, reforestation, or afforestation (if it has been without a forest in the past) depends on the value of its alternative use for agriculture, other natural areas, or even urbanization. That value, in turn, depends on (a) land-use designations, (b) land tenure and accessibility, (c) land suitability for different uses and its productivity, (d) the value of the goods produced, and (e) the local costs of labor and other inputs. As a result, the cost of climate-forestry policies (per ton of carbon dioxide) is highly location specific. In figure B3.3.1, the dark-green areas would be the least costly areas (and the red would be the most costly areas) to protect from deforestation.

**FIGURE B3.3.1 The Costs of Avoiding Deforestation in the Brazilian Amazon**
*(Spatial distribution of abatement costs of protecting forest areas threatened by deforestation)*




*Source:* Börner et al. (2010).

## Building Sectoral Pathways to Carbon Neutrality

Focusing on short-term targets (such as for 2030) without considering longer-term objectives (such as for 2050 and beyond) could lead to emission reductions based on the cheapest options—which may lack the potential to achieve complete decarbonization. It could thus result in a carbon-intensive lock-in, making it much more expensive to achieve decarbonization over the long term.

To avoid that pitfall, countries can use short-term sectoral targets to monitor progress along the four pillars of decarbonization. Doing so would ensure not only that the appropriate quantity of emission reductions is achieved over the short term, but also that the quality of those abatements is such that they really put the country on a cost-effective pathway toward decarbonization.

**TABLE 3.2 Examples of Possible Sectoral Targets for Tracking Progress toward the Decarbonization End Goal**

| Pillar | Sector | Example of target | Rationale |
|---|---|---|---|
| **Decarbonization of electricity production** | Power generation | Produce at least 30% of electricity from renewable sources by 2025 | This type of target prevents the power sector from locking into intermediate solutions, such as gas power or enhanced coal power, which do not have the potential to fully decarbonize the power sector. It also supports the development of the required technologies (e.g., solar photovoltaic and smart grid able to manage intermittency). |
| **Efficiency** | Transport | Get 50% of the population to commute by public transport (bus) in 2025 in a city | At city scale, this target helps reduce energy expenditures, congestion, and local pollution, in addition to lowering $CO_2$ emissions and building zero-carbon cities. Accessible public transit can also influence household localization choices, which have long-term consequences on energy and carbon efficiency. |
| | Building | Build 50% of zero-energy buildings in 2030 | Zero-energy buildings are needed for full decarbonization, and reduce energy bills and increase comfort. Early action is needed given the long lifetime of buildings. |
| | Cities | Plan for dense cities | Urban sprawl is mostly irreversible and locks inhabitants into carbon-intensive pathways as it makes it much more difficult to develop viable public transit systems. |
| **Fuel shifting/ substitution** | Transport | Reach 1% of electric vehicles in 2015 | Favoring electric vehicles prevents locking into marginal improvements of combustion engines, and contributes to total decarbonization as long as the electricity sector is being decarbonized at the same time. |
| | Buildings/ forestry | Use 20% of sustainable wood in new building structure by 2025 | Wood construction contributes to reaching zero carbon, if wood is produced sustainably. It is one of the options to reduce emissions from construction materials. |
| **Natural carbon sinks** | Forestry | Stop deforestation by 2017 | Deforestation (and associated loss of ecosystem services) is largely irreversible, so action in this domain cannot wait. |

Those sectoral pathways are also useful because they provide more implementation guidance for sector plans, and they make it possible to use existing regulators and institutions to design and implement the measures. Table 3.2 provides examples of possible sectoral targets—ranging from producing at least 30 percent of electricity from renewable sources by 2025 and getting half the population of a city to commute by bike in 2025 to reducing agricultural waste by half by 2030 and stopping deforestation by 2017.

So how can countries decide which sectoral targets to use? A first option is to leverage the vast literature on the topic. For instance, the International Energy Agency has published more than 20 technology road maps, covering topics such as energy-efficient buildings, wind energy, fuel economy of road vehicles, and modern bioenergy for heat and power (IEA 2015). The deep decarbonization pathways project from the United Nations Social Development Network also offers insights for 15 countries, including Brazil, China, India, Indonesia, and Mexico (IDDRI/UNSDSN 2014). When no pathways are available, countries will need to investigate new ones. The annex to this chapter reviews some of the modeling tools available to do so.

## Annex 3A: Tools to Develop Sectoral Pathways to Zero Emissions

### Economy-Wide Models: The Helicopter View to Capture Interactions across Sectors

Typically, scenarios published by the Intergovernmental Panel on Climate Change work backward from a carbon budget and assess the least-cost pathway to reach it using global economy-wide models. Those models are a particularly important tool for policy makers who are designing emission-reduction pathways, because they account for interactions across sectors (for instance, the link between power generation and transportation) and across countries (oil revenues and oil imports, impacts on trade). Those models are also often dynamic models that make it possible to investigate the timing of actions and emission reductions across sectors.

There are three broad categories of economy-wide models, each with its own strengths and weaknesses in its ability to capture different economic and physical processes:

*Technology-explicit models* represent a set of technologies, their capital costs, operation costs, and the fuel they use and generate pathways of technology mix, as a function of policy choices. They can model the impacts of climate policies leading to changes in investment patterns using performance standards, changes in energy prices, or innovation and changes in technology costs. For instance, they can estimate how the share of coal generation changes in response to the introduction of a carbon price, and the consequences on investment needs and energy prices.

Those models usually include the drivers and effects of research and development and learning-by-doing on technology costs, even though those components are highly uncertain. They are also capable of assessing how the availability of some technologies can decrease the cost of reaching certain climate targets (the International Energy Agency uses this type of model to produce its technology road maps). And most include sophisticated land-use modules that make it possible to investigate the interaction between economic policies and land-use choices (Hurtt et al. 2011). They can also assess stranded assets (Johnson et al. 2015). But most technology-explicit models take growth of gross domestic product as an input and measure mitigation costs as additional investment needs and increases in operational costs (compared with the baseline). Thus, they are not the most appropriate models for investigating macroeconomic impacts, economy-wide policies such as carbon pricing, or the effect of climate policies on international trade and competitiveness.

*Computable general equilibrium (CGE) models* provide a more detailed representation of the macroeconomic mechanisms and can investigate international links through trade and capital flows. But they often lack a detailed representation of technologies, making it difficult to explicitly represent climate policies, such as investments in public transit infrastructure or performance standards on polluting equipment (such as vehicles, appliances, or industrial equipment). Further, and most critical, CGE models often assume full market equilibrium and full use of factors of production. Consequently, they cannot capture the reality of underemployment and stranded assets and will omit some of the co-benefits expected from climate policies (World Bank 2012).

*Hybrid models* are being developed to bring together the characteristics of CGEs with those of technology-explicit models (Guivarch, Hallegatte, and Crassous 2009; Hourcade et al. 2006; Kiuila and Rutherford 2013; Schäfer and Jacoby 2006). These models are better able to connect macroeconomic mechanisms to underlying technology assumptions. In parallel, some models have included underemployment and other market imperfections (Babiker and Eckaus 2007; Guivarch et al. 2011), showing that how the labor market is modeled strongly influences mitigation cost estimates.

Beyond global models, countries may have a country-specific model that has been used to investigate local emission-reduction pathways. These pathways *downscale* the outputs of global models, allowing for better calibration and the integration of context-specific issues (such as political economy constraints and specificities of the energy system). Such models have been—or are being—developed in many high-emission countries (such as Brazil, China, South Africa, and the United States), but they are not yet available in all countries. When and where available, these national scale models can produce national road maps to guide policy action.

## Sectoral Models: Detailed Insights on Specific Issues

A variety of models are being used at the sectoral level—which is often the level at which climate change policies need to be introduced. Two examples follow:

**Energy sector models.** Arguably the most important change required to bring greenhouse gas emissions to zero is to decarbonize electricity production. Energy sector models—or models of the electricity system—can be mobilized to investigate how to do so. Take the case of power in Europe and the neighboring countries. For instance, a recent study uses the LIMES-EU model of the power sector of Europe and the Middle East and North Africa to investigate the role of long-distance transmission and storage in the transition toward large renewable shares (Haller Ludig, and Bauer 2012). The authors build a scenario leading to an almost full transition to renewables in 2050 (see figure 3A.1, left panel) and investigate the required investments in long-term transmission and storage. They show how long-distance transmission reduces the need for electricity storage and lowers electricity costs and price volatility. They also estimate the capacity required for transregion transmission (figure 3A.1, right panel).

Other models are available for other regions. For instance, the TIMES model is available at the global scale, and in many locations, such as the European Union and the United States, and for individual countries such as China and Norway.

**Urban models.** In the urban sector, land-use transport interaction (LUTI) models aim to describe how transport investments or prices can change city structures, and how changes in city structure and land-use regulation can affect transport patterns. They seek to answer the question of how public transit infrastructure and the choice of a transport pricing scheme would affect commuting patterns and localization choices (for households that decide where to live and for firms that decide where to invest). Numerous models exist (Anas 1995; Anderstig and Mattsson 1992; Elhorst and Oosterhaven 2006; Viguié and Hallegatte 2012); for a review, see, for instance, Hunt, Kriger, and Miller (2005) and Iacono, Levinson, and El-Geneidy (2008).

If a LUTI model is coupled with a global energy-economy model that provides scenarios for macroeconomic variables (such as the evolution of national gross domestic product per capita, oil prices, and labor productivity changes), it can be used to create local scenarios for cities and urban agglomerations, including scenarios for the greenhouse gas emissions from transport. As illustrated by Viguié, Hallegatte, and Rozenberg (2014), these city-scale scenarios can then be used as baselines to investigates the consequences of various urban-climate policy packages, taking into account the spatial elements and the interactions between transport, firms and households localization choices, and urban developments.

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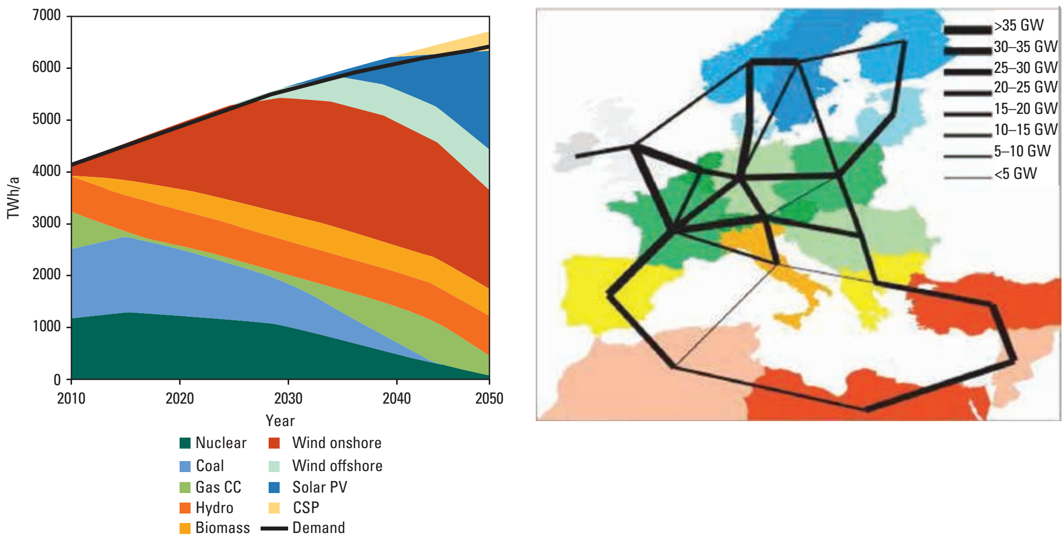
**FIGURE 3A.1 Formulating a Power Sector Strategy for Europe and North Africa**
*(Left panel: "wedge" curve showing the changing generation mix over time, aggregated across both regions; right panel: required transmission capacity across regions to support this changing generation mix)*




*Source:* Haller Ludig, and Bauer (2012).
*Note:* CC = combined cycle; CSP = concentrating solar power; PV = photovoltaic.

### The Low-Cost Approach: Aggregating Expert Views with Back-of-the-Envelope Calculations

When sophisticated models are not available, other types of less complex modeling may be needed for designing emission-reduction pathways. Thus, some studies have developed mitigation scenarios using a mix of sectoral models (such as for the energy system), simple calculations (such as using an average carbon content for various technologies), and expert opinions. Examples include some of the countries analyzed in the report *Pathway to Deep Decarbonization* (IDDRI/UNSDSN 2014).

This approach still requires collecting appropriate data (Vogt-Schilb, Hallegatte, and de Gouvello 2014). In most cases, emission-reduction potential and costs are assessed from expert surveys. To account for the long term and the role of inertia, it is also useful to include information on implementation barriers and factors that limit the pace at which emission reductions may be achieved. Including such information would be particularly helpful to decision makers if it permits identifying distinct bottlenecks (such as the availability of skilled workers) that can be translated into specific policies (such as training). It would also be critical to determine the scheduling of various actions as a function of the long-term goals.

## Notes

1. This section is based on Kalra et al. (2014).
2. In his seminal 1921 paper, economist Frank Knight offered a similar definition, distinguishing between two kinds of ignorance about our uncertain future—that which we can reliably quantify (called Knightian *risk*) and that which we cannot (Knightian *uncertainty*, which corresponds to deep uncertainty).
3. Technologies to remove carbon from the atmosphere include electricity produced from bioenergy combined with CCS (plants capture $CO_2$ from the atmosphere as they grow, and the $CO_2$ emitted from their use can then be stored underground) and changes in land use, including afforestation. Those technologies imply risks of their own. For instance, large-scale biofuels may negatively affect biodiversity and food security, carbon stored underground can leak, and poorly designed hydropower can lead to methane emissions or can divert water from other critical uses.
4. The version proposed in figure 3.3, where benefits are plotted instead of costs, is more difficult to interpret in this way.
5. The *investor's MAC curves* commissioned by the European Bank for Reconstruction and Development (NERA 2011a, 2011b, 2012) are noticeable exceptions. These curves take the point of view of private sector investors, facing among others energy subsidies, transaction costs, and high financing costs, and show what carbon price would be needed for the private sector to implement each emission-reduction option.
6. According to the Union of Concerned Scientists, about one-fifth of the United States' coal-fired power plants are "ripe for retirement," averaging 45 years of age (USC 2012).

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# PART II

## Enabling a Low-Carbon Transition: Prices and More

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# 4. Getting Prices Right

- Getting prices right will require phasing out fossil-fuel subsidies, which are bad for the environment and for fiscal policy, and are inefficient to help the poor or competitiveness.
- Carbon pricing is necessary for decarbonization to be efficient.
- Carbon pricing is not just good environmental policy, it is also good economic and fiscal policy. Carbon is a better tax base than labor and capital; it is less distortive and more difficult to evade.

Good planning is important, and part I explored how pathways toward decarbonization can be determined. The next step for governments is to enact policies to trigger the transition and to enforce those pathways, the topic of part II.

Economic incentives—such as putting a price on carbon—are critical to promoting the transition toward zero carbon, because they change behaviors in a manner that typically leads to least-cost solutions. They encourage the market to allocate efforts in an optimal manner, and they minimize the overall cost of achieving a given pollution target. On ethical grounds, pricing instruments can also be justified by a *polluter-pays* principle, whereby the individuals responsible for damages are paying for them.

This chapter discusses the steps to getting the prices right, starting with the urgent need to remove distortive subsidies—a move that is also equity improving and fiscally responsible—before turning to the argument for carbon pricing and a review of its many co-benefits.

But prices will not be enough, either because of imperfect markets or because of behavioral issues (we are aware that few humans behave like a textbook *homo economicus*), so chapters 5 and 6 examine how to complement prices with measures that can make them more effective, or how to substitute for prices when they are not. Then, in part III, chapters 7 and 8 look at social and political acceptability, arguing that getting the prices right can be done in a way that is not just equitable but actually good for the poor.

## A Necessary Step: Removing Fossil-Fuel Subsidies

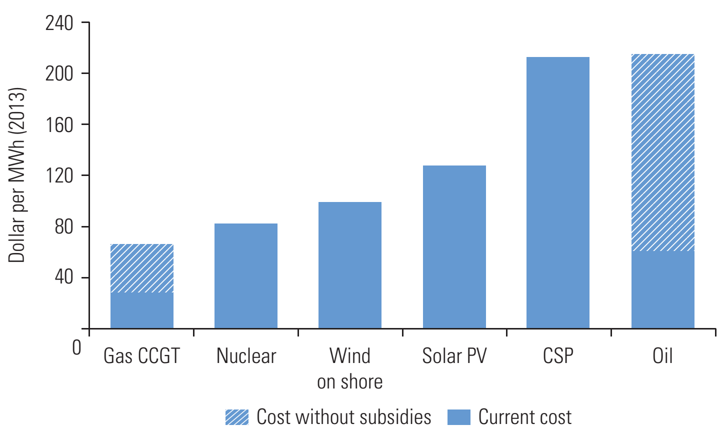
The world spent some $548 billion on direct subsidies for the consumption of fossil fuel in 2013 (IEA 2014), mostly in developing countries. That amount is likely an underestimate, as it does not include the more difficult-to-capture subsidies to producers.[1]

In addition, the Organisation for Economic Co-operation and Development estimates that its member countries spent some $55 billion to $90 billion a year on fossil-fuel subsidies over the period 2005–11, of which about 20 percent were production subsidies (OECD 2013).

Fossil-fuel subsidies have a number of damaging impacts: economic, environmental, and social. They drain public coffers and crowd out more productive public spending. Among the countries for which the IEA estimated consumption subsidies, fossil-fuel subsidies averaged 5 percent of gross domestic product, which represents an estimated 25–30 percent of total government revenue—substantially more than what those 40 governments currently spend on health (11 percent of government revenue) or education (15 percent). And where energy prices do not cover the costs borne by utilities and energy companies, chronic underinvestment causes shortages, blackouts, and reduced access to modern energy, especially for the poor. Subsidies also often result in smuggling, adulteration, and black markets (IEA 2014).

Fossil-fuel subsidies also discourage investments in clean energy and energy efficiency, tilting the balance in favor of fossil fuels and making it difficult for renewable energy and energy-efficient equipment to compete. This is particularly obvious in the Middle East where oil and gas subsidies reduce electricity prices to 30–45 percent of what they would be if full reference prices were paid (figure 4.1). Electricity generation from oil is currently one of the least-cost options in the Middle East, but it would be more expensive than wind, photovoltaic, and even concentrated solar power, absent the

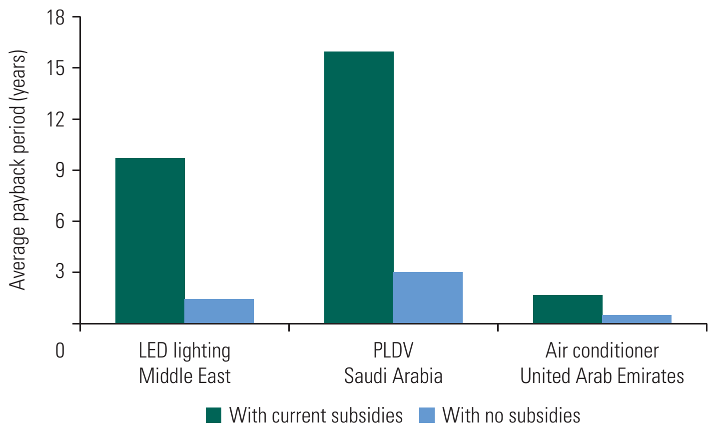
**FIGURE 4.1 Fossil-Fuel Subsidies in the Middle East Distort Incentives for Clean Energy**




*Source:* IEA (2014).

*Note:* Figure represents private generation costs. They exclude transmission and balancing cost, which are higher for wind and solar photovoltaic at high penetration rates; costs from local pollution, which are higher for production from oil; and safety costs, which are difficult to quantify for nuclear. CCGT = combined-cycle gas turbine; CSP = concentrating solar power; MWh = megawatt-hour; PV = photovoltaic (utility-scale). Generating costs are for new plants coming online in 2020; assumptions are available at www.worldenergyoutlook.org/weomodel/investmentcosts.

**FIGURE 4.2 Fossil-Fuel Subsidies in the Middle East Lengthen Payback Period for Investments in Energy Efficiency**




*Source:* IEA (2014).
*Note:* LED = light-emitting diodes; PLDV = pasenger light-duty vehicle.

subsidies. In Saudi Arabia, the removal of gasoline subsidies would reduce the payback period of upgrading from a vehicle with average fuel economy to one twice as efficient from 16 to 3 years (figure 4.2) (IEA 2014).

As a result, a number of countries find themselves subsidizing both fossil-fuel subsidies and renewables—and sometimes even taxing carbon (Whitley 2013)! Globally, total spending on fossil-fuel subsidies amount to about four to five times total spending on renewable energy—about $121 billion in 2013 (IEA 2014).

By encouraging overconsumption of fossil fuels and discouraging renewables and energy efficiency, fossil-fuel subsidies have serious environmental impacts—both global and local. The IEA estimates that phasing out consumption-related subsidies in the 40 countries covered in its data set would cut global energy-related $CO_2$ emissions by about 7 percent by 2020 (IEA et al. 2010). A subsidy phaseout would lead to reduced emissions of air pollutants, such as sulphur dioxide, nitrogen oxide, and particulate matter, which are harmful to human health and cause environmental problems, such as acid rain. The human health impacts would be substantial. Outdoor air pollution—primarily from fossil-fuel combustion—causes more than 3 million premature deaths each year worldwide. A combination of subsidy reform and corrective taxes on fossil fuels could result in a 23 percent reduction in emissions, as well as a 63 percent decrease in worldwide deaths from outdoor fossil-fuel air pollution (Parry, Heine, and Lis 2014).

Although fossil-fuel subsidies tend to occupy the limelight when it comes to environmentally harmful subsidies, others exist that also need to be tackled. In particular, reducing the hefty agricultural subsidies that prevail in many countries would also help both government budgets and the environment (box 4.1).

Moreover, fossil-fuel subsidies are singularly ineffective instruments to help with countries' competitiveness or to protect the poor—despite the fact that those are the very arguments usually invoked in their favor. A review of subsidies in about 20 countries find that they tend to be highly inequitable: only 7–8 percent of fossil-fuel subsidies benefit the poorest 20 percent of the population, whereas the wealthiest 20 percent receive on average some 43 percent of benefits (Arze del Granado, Coady, and Gillingham 2012).

However, even if fossil-fuel subsidies are inequitable in that they benefit primarily the rich, poor households could be harmed by their removal and the associated increases in energy prices. Moreover, abrupt subsidy removal can be detrimental to other development goals, such as encouraging the shift from traditional biomass to cleaner, but more carbon-intensive, fuels for cookstoves (Pachauri et al. 2013). Thus, subsidies need to be phased out progressively and to be accompanied by mitigating measures tailored to local context to ensure that the reform does not result in an increase in poverty. Fortunately, and as discussed in chapter 7, reform frees more than enough resources to allow for compensatory measures. In fact, the vast majority of successful reform episodes were accompanied by measures to help the poor (Sdralevich, Sab, and Zouhar 2014). And the drop in oil prices is creating an opportunity to eliminating subsidies (box 4.2).

### Box 4.1 Agricultural subsidies Are Also Sizable

Both developed and emerging countries heavily subsidize a number of agricultural practices and inputs, at a heavy cost to both taxpayers' pocketbook and health. For instance, China's agricultural subsidies amounted to $73 billion in 2012, of which $17 billion were targeted to agricultural inputs (Gale 2013). Such subsidies encourage farmers to overuse pesticides, water, fuel, and, most important, nitrogen-based fertilizers, which have a sizable impact on climate change (as they release nitrous oxide into the atmosphere). One recent study finds that reducing the overapplication of fertilizers, combined with better water management, could reduce Chinese national greenhouse gas emissions by 2–6 percent without compromising food production (Zhang et al. 2013).

Reforming wasteful agricultural subsidies can also free financial resources for supporting land-use-based mitigation. The recent reform of the European Union's Common Agricultural Policy redirects support to the provision of environmental public goods, such as landscapes, farmland biodiversity, and climate stability. About 30 percent of the direct payments will be devoted to increasing crop rotation, along with maintaining permanent grassland and ecological buffers. These measures could increase carbon sequestration from soils and could reduce emissions from land-use change or agricultural practices (European Commission 2011). Overall, however, the reform's mitigation potential by 2020 is estimated to be limited—reducing emissions from agricultural soils by 3 percent (from 0.5 to 1.0 million tons of carbon dioxide per year) and from agricultural practices by about 1.1 percent (7 million tons of carbon dioxide per year) (PBL 2012).

## Box 4.2 Progress on Fossil-Fuel Subsidy Reform

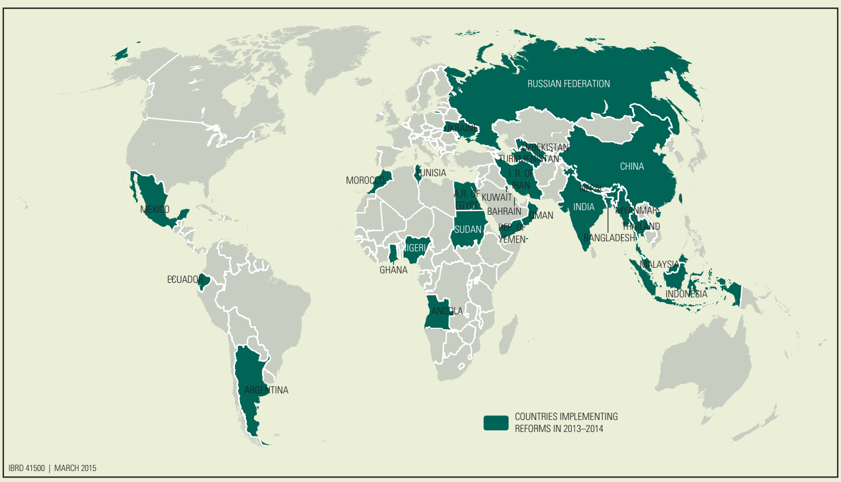
Although subsidies remain unacceptably high, progress is being made in eliminating them. In the past two years, as illustrated in map B4.2.1, more than 25 countries—many of which are in Asia—have introduced significant reforms.

Reforms are arduous and require careful preparation and planning, but success is possible. Out of 28 reform episodes that occurred over the past 20 years, 12 can be considered full successes and 11 as partial successes (often because of partial reversals or incomplete implementation; IMF 2013). More recently, a number of countries have made great progress:

- The Arab Republic of Egypt adopted significant increases in the price of transport fuels, electricity, and natural gas, which should generate $7 billion in savings ($3 billion of which are being channeled into health and education spending).
- India liberalized diesel prices, capped subsidies for liquefied petroleum gas and increased natural gas prices by 50 percent.
- Indonesia combined increases in the prices of gasoline, diesel, and electricity by 44 percent, 22 percent, and 15 percent, respectively, with a $2.6 billion package of compensation mechanisms.

In addition, China and the United States recently agreed to a peer review exercise in the context of the Group of Twenty to examine remaining subsidies with a goal to further improve their energy-pricing policies. Moreover, the current decline in oil prices provides a good opportunity to smooth reforms, while the need for fiscal tightening is an increasingly powerful motivation for many countries, notably oil producers such as Malaysia, which recently fully eliminated its gasoline and diesel subsidy.

### MAP B4.2.1 Many Countries Are Moving to Reform Fossil-Fuel Subsidies




*Source:* World Bank (IBRD 41500, March 2015).

*Source:* IEA (2014).

## The Economics of Carbon Prices—Pretty Straightforward

Carbon prices ensure that the cheapest abatement options are pursued and that firms equalize marginal abatement costs, a necessary condition for an efficient transition (Nordhaus 1991; Pearce 1991; Pigou 1932). They do so by creating incentives for markets to use all available levers to reduce emissions: the type of activity pursued, the structure of the industry or of the economy, its energy intensity, and the type of fuel chosen. Carbon prices encourage producers to decrease the carbon intensity of products, and consumers to lower their consumption of carbon-intensive goods. They encourage a shift in favor of less carbon-intensive goods (such as public transportation) and improved efficiency of existing capacities (such as carpooling and ecodriving). They promote the adoption and diffusion of existing abatement technologies. And they redirect investment toward cleaner alternatives (such as more efficient cars).

Carbon-pricing schemes are making inroads (box 4.3). But they still cover only a fraction of overall emissions. A major challenge is that they can trigger substantial resistance—as in the United States, which failed to pass national legislation, or in Australia, which recently repealed its tax. The key to greater acceptability lies in pragmatic approaches that highlight the many co-benefits of carbon pricing, and in the complementary policies discussed in chapter 5.

### Tax or Cap and Trade? Pragmatism Should Rule

As to how carbon pricing should be done, the choice should be a pragmatic one, made on the basis of what is likely to work best given a country's political and institutional setup (Goulder and Schein 2013). The main instruments to price carbon are cap-and-trade schemes and carbon taxes.

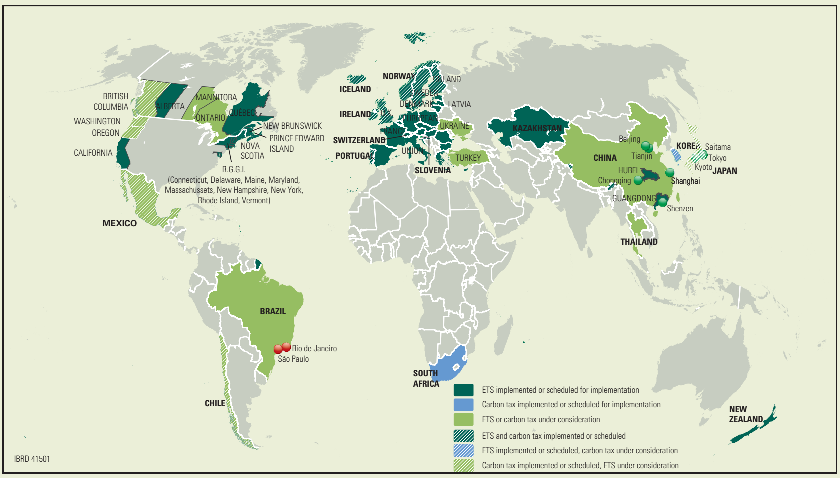
Cap and trade and carbon taxes are largely equivalent, but the local context can make one easier to implement than the other. On the one hand, a tax may be politically unpalatable—a number of jurisdictions have found it easier to implement a carbon *levy* or *fee* (box 4.4). On the other hand, a cap-and-trade scheme is more complex to establish and more costly to administer. All countries already have a tax administration in place—and a carbon tax is mostly an extension of well-understood energy or fuel taxes—while a new institution must be created for cap and trade. Further, a carbon tax would presumably be the responsibility of the ministry of finance, making it easier for the revenues to be recycled in reduced conventional taxes. With cap and trade, the regulator must not only monitor emissions but also establish a registry for allowances and keep track of allowance trades and the associated changes in ownership of allowances.[2]

Another difference between carbon taxes and cap and trade is that carbon taxes set the price but allow the quantity to fluctuate, whereas cap and trade fixes a cap on greenhouse gas (GHG) emissions while allowing the price to vary.[3] As a result, most cap-and-trade schemes have shown considerable price volatility. Between 2008 and 2014,

## Box 4.3 Gaining Momentum on Carbon Pricing

Carbon pricing is gaining momentum: 39 national and 23 subnational jurisdictions globally have implemented or are scheduled to implement carbon-pricing instruments (map B4.3.1). Chile has enacted a carbon tax expected to generate $160 million in revenues. China has launched seven local emissions-trading pilots covering the equivalent of 1.1 billion tons of carbon dioxide emissions to test different structures as it prepares to develop a nationwide carbon market that would initially cover 3 billion to 4 billion tons of carbon emissions. Together, China's pilot markets make up the second-largest carbon market in the world after Europe and are expected to attract tens of billions of dollars of investment. In an initiative initially promoted by the World Bank, some 74 national and 23 subnational jurisdictions and more than 1,000 business and institutional investors have joined a coalition of first movers supporting carbon pricing.

### MAP B4.3.1 More Countries Are Turning to Carbon Pricing




*Source:* World Bank (IBRD 41501, March 2015).

*Source:* Based on the World Bank's (2014) report *State and Trends of Carbon Pricing*, which was updated in February 2015 for the purpose of this report.

the carbon price in the EU's emissions-trading system fell from €30 per ton of $CO_2$ to €5 per ton in 2014. In California, when the 2000 energy supply crisis encouraged power companies to bring back online some older and dirtier plants, the resulting increase in the demand for nitrous oxide emission allowances drove prices from $400 to $70,000 per ton in the peak month.

Indeed, the price of allowances is very sensitive to demand shocks. If activity turns out to be lower than expected when allowances were distributed, their price will tend to drop. In addition, cap-and-trade schemes interact with *overlapping* policies, such as performance standards or feed-in tariffs, which depress the price of emission quotas by making it easier to achieve a given emissions cap (see chapter 8).

### Box 4.4 Public Acceptance of Carbon Taxes: Good Communication Helps

Let's face it, carbon taxes tend to be unpopular. One reason is that many misunderstand their purpose or benefits. In Denmark, France, Germany, Ireland, and the United Kingdom, interviews with policy makers, businesspeople, and the general public on attitudes toward environmental tax reforms find that the general public and business consider taxes solely as a means of raising revenue, rather than for their incentive effects—which they do not consider effective at influencing behavior (Dresner et al. 2006).

In British Columbia, part of the public did not understand how a carbon tax could help, given that the revenue is "given back to those who pay it" (Harrison and Peet 2012). Indeed, the fact that reforms may be flaunted as being *revenue neutral* is a common source of misunderstanding and frustration. The reality is that even if the public gets the tax proceeds back, it still has to finance the emission-reduction activities. In addition, the rebates are generally not designed in a way that compensate according to emission intensity—meaning that those who are responsible for more emissions will necessarily be hit harder. In other words, environmental reforms are usually designed to be revenue neutral from the point of view of the government implementing them, but not for each individual in society.

One solution to this unpopularity is to clearly communicate how the revenues from taxation are used. In Germany, businesses were aware of higher energy taxes but not of the associated cuts in payroll taxes. Once they knew the cuts were financed with energy taxes, businesses were less likely to disapprove of energy taxes (Dresner et al. 2006). Wording also matters. Few carbon-pricing instruments in U.S. states and Canadian provinces are officially labeled *taxes*. Instead, they are presented as *fees*, *charges*, *surcharges*, *payments*, and *premiums*, with slightly different legal meanings but sometimes greatly different public perceptions (Rabe and Borick 2012).

One way to reduce volatility is to allow for the intertemporal banking and borrowing of allowances, whereby firms can save excess allowances allocated to them for use in the future, or borrow from their future allowances. This approach has been partially implemented in the EU emission trading system, where banking is allowed without limit, and borrowing is limited to one year (to avoid relying too much on tomorrow's institutions to limit today's emissions). Other recent proposals to reduce volatility include relying on carbon stability reserves (World Bank 2014) or on price ceilings, price floors, or price corridors, beyond which the government buys or sells unlimited allowances to stabilize the price (Knopf et al. 2014).

For most other aspects, the two schemes are largely equivalent (Goulder and Schein 2013). The trading of emission quotas allows for convergence to a unique carbon price, similar to a tax. Free allowances (under a market) and partial exemptions (under a tax) can both be used to distribute efforts across firms. International competitiveness issues may also be tackled with a free output-based allowance under a cap-and-trade system and output-based rebates under a tax (see chapter 8). Finally, allowance auctioning or sales can make a cap-and-trade scheme raise revenues, just like a tax.

To trigger the right amount of investment in emission-reduction activities, carbon prices should grow predictably over time. In the case of a carbon tax, the tax rate can simply be set to grow automatically at a fixed rate above inflation.[4] A good, but theoretical, example is the carbon tax examined by the U.S. Congressional Budget Office in 2011, which was set to automatically grow at 4 percent above inflation per year (Rausch and Reilly 2012). Under cap-and-trade schemes, emission allowances should decrease predictably over time (and firms should be able to *bank* and *borrow* allowances over time, as discussed above).

## The Many Co-Benefits of Carbon Pricing

An important benefit from carbon-pricing schemes is that they *raise revenues*. In British Columbia, the carbon tax currently provides 3 percent of the province's budget (Harrison 2013), and in Sweden, it contributes 1 percent to 2 percent of the national government budget. Carbon pricing may thus offer a potential *double dividend* by providing both environmental benefits and the possibility of reducing more distortionary taxes by recycling carbon revenues: taxing *bads* (pollutants) rather than *goods* (labor and capital) should allow for a less costly tax system.

Studies suggest that the double dividend can reduce the macroeconomic cost of carbon pricing.[5] In the United States, a recent study estimates that the gross cost of cap and trade (that is, without factoring in the local or global environmental benefit) would be 0.9 percent of gross domestic product for a lump-sum rebate, but only 0.5 percent if revenues were recycled to reduce taxes (Goulder 2013). In Sweden and British Columbia, where sizable carbon taxes were implemented in 1991 and 2008, respectively, no impact on economic growth has been found (Harrison 2013).

An argument less frequently invoked in favor of carbon pricing, but one that adds to the potential double dividend, is that it offers *a good tax base*, at least over the short and middle term. It does so because a carbon price is difficult to evade. First, carbon sources are concentrated, making it easy to measure and monitor physical units of energy at the supplier level. In the United States, tax collection covering 80 percent of U.S. GHG emissions, and nearly all $CO_2$ emissions, could be accomplished by monitoring fewer than 3,000 points: 146 oil refineries, 1,438 coal mines, and 500 natural gas fields (Metcalf and Weisbach 2009). As a result, monitoring a carbon-pricing scheme is much easier than monitoring other tax bases, such as hours worked, profits earned, or personal income. Second, an entire infrastructure of meters, bills, and storage tanks are already available to objectively measure how much energy is consumed. Third, commercial users have powerful incentives to deduct their energy expenditures, making it easy to catch cheating suppliers. Third, the price of energy is typically well established, occurring in transparent marketplaces, which makes it more difficult to report inflated prices as a mean to evade taxes (Liu 2013).

The evidence supports the idea that carbon, or energy more generally, is a good tax base. In Sweden, evasion of the carbon tax is less than 1 percent, substantially less than evasion of the value added tax. In the United Kingdom, evasion of the excise tax on diesel is about 2 percent, as opposed to 9 percent for the corporate tax, 11 percent for the value added tax, and 17 percent for income taxes (HM Revenue & Customs 2014). Such relatively high compliance would particularly benefit the large emitters of GHGs—such as China, India, and Indonesia—that suffer from high tax evasion (Gordon and Li 2009).

In addition, carbon taxes reduce incentives for firms and individuals to stay in the informal sector—keep in mind that although conventional taxes (such as wages, sales, or profits) apply only to the formal sector, a fuel tax applies equally to both the formal and the informal sectors. When revenues from the carbon tax are used to reduce other conventional taxes, the gap between the tax burden in the formal and the informal sectors decreases, which in turns reduces the incentive to join the informal sector (Bovenberg 1999; Goulder 2013). Carbon taxes would also boost total welfare by freeing up resources previously spent on tax evasion—possibly significantly lowering the cost of the tax. One new study estimates that in countries with higher tax evasion, such as China and India, reduced tax evasion can divide the cost of a carbon price by a factor of close to 10 (Liu 2013).

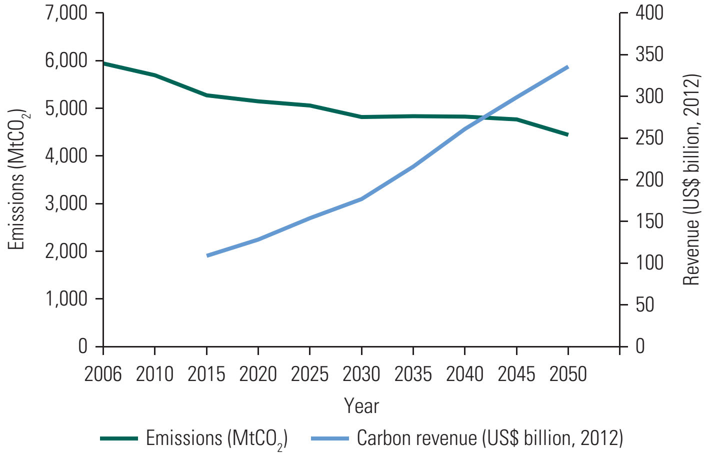
An interesting twist here is that some contend that since the objective of a carbon tax is to reduce GHG emissions, its very purpose is to erode its own base (that is, reduce or even eventually eliminate fossil-fuel consumption). That argument is valid over the long term: by the end of the century, once the final objective of carbon neutrality is achieved, carbon taxes should no longer be a source of revenue. But in the short and middle term, carbon prices are a good source of revenue.

In fact, the expected effect of a carbon tax is not to decrease emissions immediately or brutally, as that would be a costly shock to the economy. Instead, a carbon price is expected to first progressively reduce the pace at which GHG emissions are growing until that growth stops and emissions finally start to decrease. Also, the best design for a carbon price is to make it grow exponentially over time. Over the first few decades, the growing tax rate can thus offset the decreasing base of GHG emissions. For instance, as figure 4.3 shows, if the United States introduced a carbon tax at $20 per ton in 2012 and let it rise by 4 percent above inflation per year, the tax would reduce emissions from 5.7 billion to 4.8 billion tons of $CO_2$ per year between 2010 and 2050, while increasing revenue from $110 billion in 2012 to $340 billion in 2050 (Rausch and Reilly 2012).

## Incentives for Land-Use-Based Mitigation

Although carbon-pricing schemes seldom cover land uses—exceptions include carbon markets in California, Kyoto, and New Zealand—many countries have implemented

**FIGURE 4.3 A Rising Rate Can Offset a Declining Tax Base**
*(Estimated carbon tax revenue and GHG emission reductions from a U.S. carbon tax starting at $20 per ton of $CO_2$ in 2014 and growing at 4 percent above inflation per year)*




*Source:* Adapted from Rausch and Reilly (2015).

performance-based payments that mostly involve public funds to reward landscape actors for reducing emissions or sequestering carbon.

Currently, more than 300 payments for ecosystem service schemes have been established worldwide to support carbon sequestration, biodiversity, watershed services, and landscape beauty. Brazil's Bolsa Floresta program offers a monthly payment to low-income households if they commit to zero deforestation and enroll their children in school (Ecosystem Marketplace 2015). Ecuador's Socio Bosque program pays land users for the conservation of natural forests. And China's Grain for Green program aims to convert 20 million hectares of cropland and barren land on steep slopes into tree-based plantations—with early results suggesting enormous carbon sequestration benefits in soils and tree biomass (Chang et al. 2011; Chen et al. 2009).

All together, the largest national programs in China, Costa Rica, Mexico, the United Kingdom, and the United States provide payments of more than $6.5 billion per year (NCE 2014).Yet such national-level initiatives face two main challenges in getting the price right. It is difficult to define the payment level that will compensate the many different landscape actors for not pursuing more profitable activities (such as conversion of forestland). And because of limited national funds, such schemes are unlikely to preserve and increase carbon sinks at the speed and scale needed. Thus, international incentive mechanisms—such as for reducing emissions from deforestation and forest

### Box 4.5 Global Mechanisms to Cut Emissions from Deforestation and Forest Degradation

Increasing international attention and funding have been raised for reducing emissions from deforestation and forest degradation and for other forest-related mitigation activities. At the Cancún meeting of the United Nations Framework Convention on Climate Change in 2010, member countries agreed to establish an international mechanism, whereby developed countries would pay low-income and middle-income countries in the tropics for five types of forest-related mitigation activities: (a) reducing emissions from deforestation, (b) reducing emissions from forest degradation, (c) conservation of forest carbon stocks, (d) sustainable management of forest, and (e) enhancement of forest carbon. That mechanism is known as REDD+ in reference to the fact that it is broader than an earlier scheme to reduce emissions from deforestation and forest degradation, known as REDD. REDD+ can be implemented domestically through a mix of instruments, including law enforcement and payments for ecosystem services.

The REDD+ financing architecture is still under discussion within the Framework Convention. Most of the existing funding related to REDD+ is being made available at the bilateral level, mainly from developed countries. Norway has pledged $1 billion for the Amazon Fund, which includes incentives for small-scale farmers to invest in more intensive and profitable crop and livestock systems (Nepstad et al. 2014); another $1 billion in exchange for a two-year moratorium in Indonesia on new concessions for clearing or logging of peat and old-growth forest and the eventual definition of performance-based payments (Luttrell et al. 2014); and $250 million for Guyana. Germany has established a program of about $50 million for early movers in reducing emissions from deforestation and forest degradation (FMECD 2012).

There are also several multilateral funds that can provide performance-based payments for land-use-based mitigation. They include the Carbon Fund of the World Bank's Forest Carbon Partnership Facility, the Forest Investment Program as part of the Climate Investment Funds, and the BioCarbon Fund.

degradation and for other forest-based mitigation activities (REDD+)—are being developed (box 4.5).

## Notes

1. The International Energy Agency (IEA) measures subsidies only at the consumption level by calculating the difference between the reference price in a market-based transaction and the actual price charged to consumers. The IEA's estimates represent a lower bound because producer subsidies are not necessarily captured. For a discussion of fossil-fuel subsidy methodologies, see Kojima and Koplow (2015).
2. However, cap-and-trade schemes are easier to link across jurisdictions, helping firms in one place pay for emission reductions in another place, as the joint Québec-California cap-and-trade system illustrates (World Bank 2014).
3. On the one hand, the fact that carbon markets make total emissions exogenous is appealing for cost-effectiveness, for instance, for governments willing to stick to announced targets (Weitzman 1974). On the other hand, exogenous prices help avoid problematic interactions

with other climate policies and avoid large wealth transfers to fossil-fuel-exporting countries (Goulder and Schein 2013).

4. The ideal policy is to make the tax rate grow at the current risk-free interest rate, so that the tax increases are slower during slowdowns and faster during economic booms, and the present value of the carbon tax remains constant over time.
5. See the collection of papers and presentations made at the Mercator Research Institute on Global Commons and Climate Change's Public Finance Workshop in May 2013. http://www.mcc-berlin.net/en/events/event-detail/article/public-finance-workshop.html.

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# 5. Building Policy Packages That Are Acceptable, Credible, and Effective

- Policy packages are needed that complement prices in cases of multiple market and government failures—or that substitute for them where prices are ineffective at changing behaviors.
- These policies need to ensure that needed technologies are available and affordable, the necessary infrastructure is in place to offer viable alternatives, and that other factors, such as behavior, that reduce the impact of price incentives are taken care of.
- Even in the absence of a carbon price, these policies will deliver emission reductions. Further, they lower the carbon price required for decarbonization and make the economy more energy efficient, thereby reducing economic and social disruptions from climate policies and increasing their acceptability.

Carbon prices are necessary for the efficiency of the transition, but, alone, they will not be enough to generate the needed shifts in investments and behaviors. The reason is because carbon prices can address only one market failure—the fact that the costs of greenhouse gas (GHG) pollution is not captured by markets. Yet in reality, many market and government failures combine to make climate change such a complex problem. Thus, complementary measures and investments are needed to make individuals and firms more responsive to prices.

This chapter explores a variety of policies that would complement prices, or that would substitute for them where they are ineffective instruments. It focuses on three areas: (a) policies to ensure that the needed technologies are available and deployed at the required pace and cost, (b) infrastructure to offer viable alternatives to carbon-intensive options, and (c) behavioral issues and other implementation barriers.

Together, those policies accomplish two objectives (Bertram et al. 2015; Hallegatte, Fay, and Vogt-Schilb 2013). First, they directly reduce emissions and help countries progress toward full decarbonization. That objective is particularly important in sectors where pricing solutions remain ineffective or insufficient. For example, a carbon price cannot replace energy-efficiency regulations in buildings. Second, those policies reduce the carbon price needed to achieve the transition to carbon neutrality, making it less disruptive and more acceptable.

## Ensuring the Needed Technologies Are Available and Affordable

The transition to a low-carbon economy will require substantial innovation. Although existing technologies should be enough to keep the world on track for warming below 2°C until 2050, new technologies will be needed beyond 2050, such as biofuel electricity production with carbon capture and sequestration (CCS) (Guivarch and Hallegatte 2013; IPCC 2014; Pacala and Socolow 2004; Tavoni and Socolow 2013; World Bank 2010). Those technologies do not exist today—the most advanced are barely at the pilot stage—and are unlikely to emerge without a lot of investment in research and development (R&D) and pilot projects. Further, even the technologies will need to be fully deployed and brought to scale. So the technology challenge of a low-carbon transition includes both innovation and deployment.

### The Innovation Challenge

Green innovation suffers from a double market failure. The first is the environmental externality, which can be tackled using carbon-pricing instruments. The second is the same *knowledge externality* that plagues all innovation and results in levels of innovation that are below what is socially desirable (Hausmann and Rodrik 2003). Because new knowledge can be acquired at a low cost by competitors, innovations generally produce benefits beyond what their inventor can fully capture.[1] As a result, government action is required to promote socially optimal levels of new knowledge production, research, or training (Dutz and Sharma 2012).

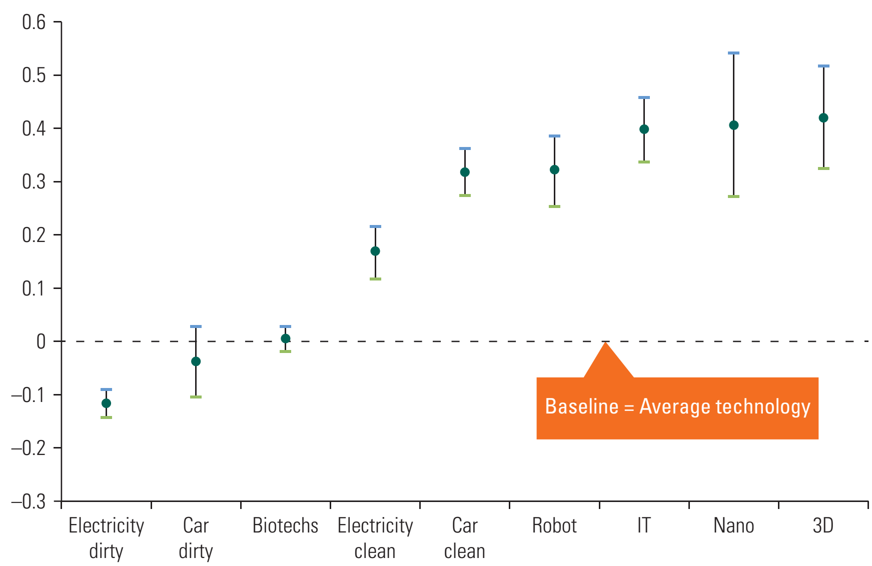
Furthermore, economic actors generally prefer to do what they are already set up for and are good at, so they tend to innovate and invest in technologies that are already mature and have a large market share, thereby locking in carbon-based technologies and sectors (Acemoglu et al. 2012). One solution might be to impose a carbon price higher than the marginal cost of carbon, but that would impose unnecessarily high costs in the short term. Instead, the optimal strategy is to kick-start the transition by temporarily supporting investment in low-carbon technologies and sectors (Acemoglu et al. 2012; Rosendahl 2004).

There are many other reasons governments may want to target support to green innovation. First, the knowledge externality argument is in fact greater for green innovation, given that returns on low-carbon innovation are likely to be realized over longer time horizons than in other domains (such as information and communication technologies). Green innovation may thus be less well supported by traditional intellectual property rights instruments such as patents and may require additional encouragement. Although a 20-year patent is more than sufficient for cell phone innovations that offer a rapid return on R&D investment, such a time horizon may be too short to motivate investments in innovation in solar panels or electric cars (Gerlagh, Kverndokk, and Rosendahl 2014).

Second, green innovation appears to offer more growth benefits than brown innovation (Dechezleprêtre, Martin, and Mohnene 2013). Clean technology R&D has economic benefits that spill over throughout the economy via new knowledge diffusion—comparable with those from robotics, information technology, and nanotechnologies, and is much larger than those from fossil-based technologies (figure 5.1). In other words, new clean technologies may represent a source of economic growth as large as that of other frontier-emerging technologies, and possibly some 50 percent higher than fossil-based technologies. That is likely because green innovations have broader applications throughout the economy than dirty innovation, and they tend to be radically new compared with innovation in the brown technologies, which tend to be more incremental.

Third, targeted support is needed when the potential of one low-carbon technology is deemed to be superior to another (Bramoullé and Olson 2005; del Rio Gonzalez 2008). Specific support to solar energy production—as opposed to other carbon-free electricity production technologies such as wind power—is justified by the larger potential of this technology to solve the clean-energy challenge at low cost. The current relatively high costs make it unlikely for solar energy to be massively deployed with only horizontal (nontargeted) support to carbon-free electricity production or a carbon price (which would trigger investments in cheaper wind energy). A feed-in

**FIGURE 5.1 Green Innovation Generates Much Greater Knowledge Spillovers than Brown Innovation**




*Source:* Adapted from Dechezleprêtre, Martin, and Mohnen (2013).

*Note:* Knowledge spillovers are measured by patent citation and are normalized in an index set to a baseline of zero for biotechnology, the technology that happens to have the average spillover.

tariff that favors solar over wind may thus be more efficient in the medium to long run than technology-neutral feed-in tariffs (designed as a function of GHG emissions of electricity production) that incentivize electricity providers to choose today's cheapest low-carbon technology (Azar and Sandén 2011).

Fourth, sometimes carbon prices cannot be implemented, or are implemented at suboptimal levels. In such a case, direct support may be desirable, especially in sectors where green technologies may eventually compete with carbon-based technologies even with no or insufficient carbon pricing. One example is hybrid cars. Another is photovoltaic solar electricity, which is already competitive in some markets (such as off-grid, small-scale electricity supply) and may become competitive as soon as 2020 in countries with the appropriate potential (de La Tour, Glachant, and Ménière 2013; IEA 2014a).

Fifth, innovation in low-carbon technologies facilitates the eventual adoption of carbon prices. Economic actors are more likely to accept a carbon price if there are alternatives to carbon-intensive technologies and lifestyles—such as an affordable plug-in hybrid electric car. And when alternatives are palatable, lower price hikes are needed to change behaviors.

To date, innovation in low-carbon technologies has been concentrated in a few leading countries, such as Germany and the United States (World Bank 2012). Elsewhere, the focus is on adapting and tailoring those technologies to the local context. Governments can help support dissemination of new technologies, notably through education policies to ensure that there are enough scientists and engineers locally to adapt the technologies. Access to low-carbon technologies can also be improved with openness to international trade. Eliminating tariff and nontariff barriers in developing countries would significantly increase the diffusion of energy-efficient lighting and renewable power generation (World Bank 2008).

Technology and skill transfer also occur through the movements of people attached to multinational corporations or from the diaspora and through the purchase of manufacturing equipment on global markets. That channel was critical in the ability of Chinese producers to become world leaders in photovoltaic panel production (De La Tour, Glachant, and Ménière 2011). Also, Indian windmill manufacturer Sulzon established R&D offices in Germany and the Netherlands, making it easier for its staff to learn from local expertise.

Specific trade policies can accelerate technology transfers, for instance, by requiring local content and technology transfers when contracts are signed with more advanced countries. For instance, when Morocco hired a French company to build the Casablanca tramway and provide high-speed train connection with Rabat, the contract included technology transfers and the construction of a local factory to produce parts (beam and wire) for the domestic and international markets.

Finally, countries lagging in the innovation process can become innovators themselves. In some cases, low-carbon technologies may be sufficiently different from traditional alternatives that new countries do not start at a disadvantage in the competition. For instance, traditional automakers have accumulated more than a century's worth of expertise on technologies, such as internal combustion engines and mechanical transmission. A shift to electric vehicles would reduce their technology advantage and make it easier for new entrants to compete in the automobile sector.

## The Deployment Challenge

The mere existence of carbon-free technologies does not ensure that they are scaled up at the pace and to the extent needed for both availability and affordability. Rather, specific policies may be needed to encourage *sunrise* sectors or technologies and help them take on the many challenges that any new technology or product would face (Hallegatte, Fay, and Vogt-Schilb 2013).

### *The Obstacles*

Such policies should tackle several obstacles to technology deployment.

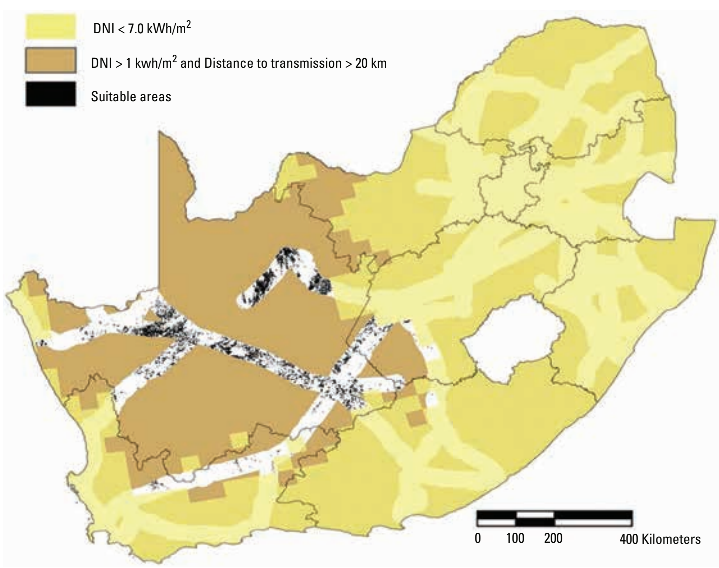
***Policy credibility.*** A price signal is unlikely to provide enough incentive to deploy existing technologies. For instance, given the expected lifetime of power plants, a credible carbon price pathway would need to be announced at least three decades in advance to spur the optimal amount of investment in low-carbon power plants. But doing so is difficult, because governments have a very limited ability to commit over such long periods (Brunner, Flachsland, and Marschinski 2012; Helm, Hepburn, and Mash 2003)—as Australia's recent reversal on carbon taxes illustrates. Thus, where reducing emissions requires dealing with investments with long-term consequences (such as infrastructure, R&D, and long-lived capital), additional regulations, norms, or direct investments are needed (Vogt-Schilb and Hallegatte 2011).

***Economies of scale and latent comparative advantage.*** Technology deployment is hampered by market failures, such as economies of scale and latent comparative advantage—that is, a comparative advantage that can be realized only if public action allows the economy to get out of a low-productivity trap. To correct such market failures, governments may need to temporarily support the uptake of some technologies (Harrison and Rodríguez-Clare 2009; Kahn and Blankenburg 2009; Rodrik 2004). The case of solar panels in China illustrates the potential of green sectors that are based on a latent comparative advantage that could not have grown without initial support. It also illustrates the role of increasing returns, because the recent drop in production costs can be largely explained by scale effects (including direct scale effects and material and equipment discounts) rather than by labor costs or land subsidies (Goodrich et al. 2013).[2] In this context, capturing those opportunities may require that governments *discover* comparative advantages of their country through exchanges between government organizations and the private sector (Harrison and Rodríguez-Clare 2009; Rodrik 2004).

In some cases, a latent comparative advantage can be observed ex ante and thus can justify a targeted policy, as has been occurring with large-scale renewable energy projects in North Africa. Even though the first projects are more expensive than an equivalent fossil-fuel-based production (for example, the Ouarzazate concentrated solar plant in Morocco), some countries hope to reduce the price of solar technologies to capture the advantage that their climate, solar irradiance, and proximity to the large European market offer and to transform solar power into a cheap resource and a possible new source of export revenues. Renewable energy potential depends on observable country conditions, such as climate and geographic characteristics. But the ability to connect to markets is also critical. Take the case of South Africa, where policy makers must weigh both solar irradiance and closeness to transmission lines when deciding where to install large solar power plants (map 5.1).

***Coordination failures.*** Climate strategies are by essence multisectoral and require interagency, intersectoral, and public-private coordination (Murphy, Shleifer, and Vishny 1988; Okuno-Fujiwara 1988; Pack and Westphal 1986; Rosenstein-Rodan 1943). Increasing the share of electric cars, for instance, requires long-term coordinated

**MAP 5.1 Pinpointing Where to Install Large Solar Power Plants in South Africa**




*Source:* Fluri (2009).

*Note:* DNI stands for *direct normal irradiance*, a measure of how much solar energy can theoretically be captured at ground level. Lighter share corridors are existing transmission lines. Areas in white are not suitable locations due to other reasons (e.g., land is too steep). Suitable areas have good DNI, proximity to transmission lines and appropriate land (flat enough with vegetation that is not under threat and a suitable land use profile).

investments by carmakers, electricity providers, and infrastructure providers—which, in turn, necessitates adequate institutions (both market and regulatory) and possibly some targeted policies.

### *The Policy Instruments*

How can policy makers tackle these obstacles to deploying green technologies? A solution is to combine an economy-wide carbon price with sectoral policies that aim specifically at encouraging investment in long-lived equipment or at coordinating multisector strategies. Such policies complement carbon prices by ensuring that they are effective. But they also deliver emission reductions even in the absence of a carbon price. And where prices are distorted, these measures redirect new investments toward more efficient technologies and production capacity. They progressively transform the economic system into a more efficient one that is able to remain competitive when carbon prices are introduced (Rozenberg, Vogt-Schilb, and Hallegatte 2014). It may therefore be easier to start with such instruments, which include the following.

***Performance standards.*** Performance standards are commonly used for cars and other light-duty vehicles. Currently, 36 countries have imposed performance standards on light-duty vehicles (Brazil, Canada, China, the EU countries, India, Japan, Mexico, the Republic of Korea, and the United States), and five are studying performance standards for heavy-duty vehicles. The Global Fuel Economy Initiative is working with 20 countries to help them increase the efficiency of their car fleets. Other sectors where performance standards are used include energy-efficient lighting, household appliances, and industrial equipment. Through the United Nations Environment Programme–Global Environment Facility en.lighten initiative, 55 countries have committed to implement policies and measures that will reduce inefficient lighting by 2016. Energy-efficiency requirements have also been integrated in building codes, mostly in developed countries. Scaling up performance standards for buildings, or key parts of buildings (such as windows and ventilations systems), is likely to be critical for achieving net zero emissions in the building sector (Saheb et al. 2013). Performance standards are particularly efficient when they are announced in advance: doing so allows firms to develop new products that meet the standards (IEA 2012). Thus, performance standards not only reduce emissions, they also redirect private R&D expenditures toward low-carbon options and technologies.

***Fiscal instruments (including feebates).*** Fiscal incentives are often successfully used to improve the energy efficiency of cars (such as feebate programs in European countries and an adjusted value added tax [VAT] in South Africa), lighting and appliances (such as VAT adjustments in Ghana), and buildings (such as subsidized loans to finance energy-efficiency improvements). They complement mandatory standards and labeling policies. They also sway purchase decisions and in some cases production decisions and retail stocking decisions toward high-efficiency products. VAT reductions for efficient equipment—notably, compact fluorescent lamps (CFLs)—constitute the most common application for a tax-reduction strategy outside developed countries. Well-designed feebates have the advantage of being self-financed. Other possible fiscal instruments include tax increases for inefficient technologies, subsidies, rebates, and giveaways (box 5.1). Given that they progressively transform the production system, the fiscal incentives prepare the economy and the public to more easily implement or phase in higher carbon prices in the medium term (Rozenberg Vogt-Schilb, and Hallegatte 2014). Moreover, they do not need to be permanent. In 2003, Ghana eliminated the VAT for CFLs but reintroduced it when incandescent bulbs were phased out and CFLs became the most common technology on the market. Subsequently, the government eliminated the VAT for LEDs.

***Regulatory mandates (renewable portfolio standards, or RPS)*** require electricity producers to include a minimum share of renewable energy in their output mix. They are more efficient when used in combination with tradable renewable certificates, whereby utilities with excess renewable production can sell certificates to utilities that produce too little. RPS are used in most U.S. states (IEA 2014b)—typically to regulate renewable energy production in the electricity sector but also to mandate the usage of biofuels for transportation. In Chile, an RPS requires that 5 percent of electricity sold comes from renewable sources (excluding large hydro) by 2015 and up to 10 percent by 2024. In the United Kingdom, a similar program called *renewable obligation* sets an objective with regard to renewable production but gives producers an option to buy unlimited renewable certificates from the government at a fixed price.

A downside of regulatory mandates is their lack of flexibility, which can translate into high compliance costs. For instance, the United States has set a mandate for retailers to blend bioethanol into gasoline. During the recent economic slowdown, reaching the blending mandate—expressed as an absolute volume, not a proportion of gasoline sold—was made more difficult by the fact that gasoline consumption was stagnating. More flexible options include using a target expressed as the minimum of a given volume and a proportion of gasoline sold, or, better, using price instruments, such as fiscal incentives, discussed above, instead of quantity instruments (see also chapter 8).

***Pilot projects*** partially funded, and sometimes coordinated, by the government help lower the cost of capital for risky projects. Morocco hosts two large-scale pilot projects to demonstrate the feasibility of concentrated solar power plants. In Brazil, China, and India, this approach has been used, in the form of public auctions, to encourage the deployment of renewable power plants (Elizondo Azuela et al. 2014), and in many European countries such as France and Denmark, it has recently been used for large-scale offshore wind power. Pilot projects are also used around the world to support the uptake of carbon capture and storage (MIT 2015).

***Skills and education.*** Climate policies affect the demand for skills in three ways: (a) structural change increases the demand for skills specific to expanding industries,

## BOX 5.1 Fiscal Instruments to Encourage Demand for Clean Technology Products

### Cars

In *France*, the Bonus-Malus program paid 2009 buyers of cars emitting a maximum of 160 grams of carbon dioxide ($CO_2$) per kilometer (209 grams per mile) a bonus ranging from $250 to $6,400, depending on emissions levels. A fee for high-emission vehicles was introduced to finance the scheme. The feebate program resulted in an immediate drop of 7 grams of $CO_2$ per kilometer for new vehicles. Fees and rebates have been updated frequently, because the success of the measure was underestimated and the initial structure led to a high budgetary cost. Today, rebates focus on providing sizable subsidies to very efficient vehicles ($4,500 for vehicles that emit fewer than 60 grams per kilometer), and fees for inefficient vehicles reach almost $9,000. Similar feebate programs have been enacted in other European countries (including Belgium, Germany, the Netherlands, Sweden, and the United Kingdom), at the state level in the United States, and at the provincial level in Canada.

### Energy-efficient lighting

In *Tunisia*, exemptions from the value added tax and minimum customs duty on the import and production of compact fluorescent lamps (CFLs) and a range of other energy-efficiency equipment materials has been in place since 1995. A tax has been introduced on incandescent lamps (10 percent in 2007, 30 percent in 2008, 50 percent in 2011), generating revenues that are used for subsidizing CFLs. In the *Republic of Korea,* domestic residents seeking to invest in energy-saving facilities, as designated by the president's executive order excluding investments in secondhand equipment, can apply for a tax waiver (20 percent of total investment cost) from income or corporate tax. The tax incentive covers investments across sectors. Lighting products targeted include single-phase electric motors, fluorescent lamps, ballasts for fluorescent lamps, CFLs, high-luminance reflectors for fluorescent lamps, and sensor lighting equipment.

### Appliances

In *Mexico,* the Electric Power Savings Trust Fund and the Federal Electricity Commission started the Program for Financing of Electric Energy Saving, which finances the substitution of old, inefficient refrigerators and air conditioners with modern and more efficient equipment. The program also provides financial support for thermal insulation of homes. The cost of more efficient lighting is financed through a credit paid on electricity bills, which is largely recovered because of reduced electricity costs. The first phase of the program ran from 2002 to 2006, with approximately 30,000 homes being insulated and about 130,000 refrigerators and 623,000 air-conditioning units being replaced.

In *China,* an upstream subsidy program began with a CFL promotion program in 2008. A total of 210 million subsidized CFLs were sold to consumers between 2008 and 2009, resulting in estimated electricity savings of 8,800 gigawatt-hours each year. In June 2009, the government extended the incentive program to air conditioners, offering subsidies of $72 to $122 per unit for efficient products, rated as grade 1 in the Chinese label system and $45 to $95 per unit for grade 2 products. Local governments were encouraged to provide additional subsidies. By early February 2010, about 5 million subsidized high-efficiency air conditioners had been sold, leading to a reduction of 1.5 billion kilowatt-hours of electricity. In June 2012, the Chinese government extended the program to include other appliances: TVs, refrigerators, washing machines, and water heaters.

such as renewable energy, and reduces the demand for skills, such as those for coal mining; (b) new occupations are emerging, such as photovoltaic fitters; and (c) the content of many jobs is affected by companies' stronger focus on efficiency and clean energy (Strietska-Ilina et al. 2011). For instance, increasing carbon sinks requires new practices that go beyond traditional agricultural techniques, such as soil and water conservation, agroforestry, and grazing land management. That said, few unique green skills exist, and the observed skill scarcity arises mostly from generic failings in education and training. Those failings range from poorly functioning education systems and the mismatch between students' choices of discipline and the needed skills to the lack of incentives for employers to invest in developing the transferable skills of their workforces, the poor's lack of access to training, and the stickiness of relative pay rates (World Bank 2012). The transition toward a low-carbon economy may however exacerbate those issues, making it even more urgent and important to increase enrollment in technical secondary and tertiary education in developing countries and to improve the quality of education in those domains.

Another policy that can be introduced in parallel or in anticipation of the introduction of a carbon price is to increase investment in the infrastructure that is needed to support a more energy-efficient, less carbon-intensive economy.

## Ensuring the Needed Infrastructure Is in Place

People's ability to change their behavior in response to a carbon price or energy tax depends on the existence of an alternative—preferably, a safe, convenient, inexpensive one. But such alternatives often depend on the appropriate infrastructure being available. Take the following two examples.

***Transport and urban forms.*** Transport is responsible for 14 percent of global GHG emissions, and the sector is considered as one of the most difficult to decarbonize—notably because of its reliance on large-scale infrastructure (such as road networks, urban forms, and railways). Two (nonexclusive) options are usually considered. The first is to maintain current shares of various transport modes but to replace vehicles by carbon-free vehicles such as electric cars (charged with carbon-free electricity)—a move that will require large investments in electricity-charging infrastructure. The second is to modify modal shares by reducing the number of individual vehicles and increasing public transit. But this option requires urban forms that favor public transit, namely, higher density around train stations and bus stops.

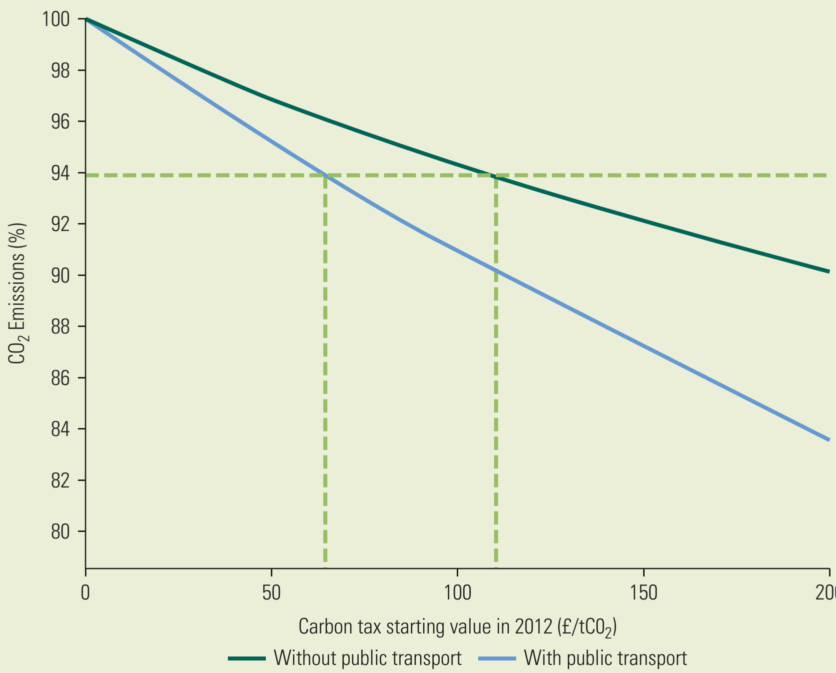
As it turns out, studies find that urban planning that promotes densification and investments in public transportation infrastructure substantially increases the elasticity of energy demand to carbon price. In other words, prices will work better in changing behaviors if combined with infrastructure development (box 5.2). For example, the huge difference in the availability of public transport infrastructure may explain the

## BOX 5.2 Combining Carbon Pricing with Infrastructure Development in Paris

Just how important is the existence of a public transit system for making carbon prices change behaviors? A recent study of Paris concludes that it is very effective (Avner, Rentschler, and Hallegatte 2014). The authors calibrate a transport–land-use model with two different cities: Paris as it existed in 2010 and a counterfactual Paris in which no public transport infrastructure would have been built. They then compare the resulting carbon dioxide ($CO_2$) emissions and their response to carbon pricing. They find that a €200 per ton of $CO_2$ carbon tax results in emissions dropping by 16 percent when public transport is available, compared with a little less than 10 percent without public transport (figure B5.2.1). That means that in the medium run, a €200 per ton of $CO_2$ carbon tax is over 60 percent more effective when a modal shift is possible, and in the short run (until 2014), it is 130 percent more effective.

How about the carbon tax required to achieve a given abatement objective? The study finds that without public transport, achieving a 6 percent decrease in $CO_2$ emissions would require

**FIGURE B5.2.1 Carbon Taxes Work Best When Public Transport Is Available**
*(Relative impact of carbon taxes on commuting-related emission levels in the Paris metropolitan area in 2020 for scenarios with and without public transport)*




*Source:* Avner, Rentschler, and Hallegatte (2014).

*Note:* Where the horizontal green dashed line crosses the blue and green curves, we can read on the X-axis the corresponding carbon tax starting values that must be implemented in 2012 to achieve a 6 percent reduction in $CO_2$ emissions.

(*Box continues on the following page.*)

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**BOX 5.2 Combining Carbon Pricing with Infrastructure Development in Paris (continued)**

almost double the carbon tax compared with the scenario in which public transport exists (€115 per ton of $CO_2$ instead of €65 per ton of $CO_2$). But even a tax of €65 per ton of $CO_2$ is large compared with the one debated in France in 2008 (only €17 per ton of $CO_2$). Yet this bill failed in part because the financial burden on commuters living far from public transport was considered to be too high.

The limited impact of the carbon tax in reorienting behaviors toward more sustainable location and commuting decisions can be explained by the importance of the time cost component compared with the monetary component of commuting costs. For instance, a recent study finds that the cost of time in 2010 represents up to 90 percent of the generalized costs of transport in the Paris urban area (Viguié, Hallegatte, and Rozenberg 2014). Thus, even a strong increase in fuel prices will only marginally affect generalized costs and travel behavior. In contrast, an efficient public transit system avoids congestion and offers shorter trips.

gap between low gasoline taxes in the United States (with limited availability of public transport and high dependence on private cars) and high gasoline taxes in Europe (with much lower reliance on individual cars). In the absence of alternatives, public acceptability of gasoline taxes is much lower in the United States.

As emphasized in chapter 3, a key aspect of transportation infrastructure is that it takes time to develop. Moreover, once a city has developed and sprawled without a public transit option, it is extremely difficult, if not impossible, to retrofit it (since good public transit requires density). For cities to enjoy the benefits of good public transport infrastructure, they must therefore act early. Early action is particularly important for developing countries with fast-growing new cities: they face a window of opportunity to act.

***Electric grid and renewable power.*** Another typical example is an electricity transmission grid, which is especially critical for countries weighing massive expansions of their renewable generation capacity (Haller, Ludig, and Bauer 2012). In India, the wind resource potential is an estimated 3,000 gigawatts, or approximately 12 times the current total installed electricity production capacity (Phadke, Bharvirkar, and Khangura 2011). China is considering a solar photovoltaic road map for 1,000–2,000 gigawatts of photovoltaic developments by 2050 (Grimes 2014). Renewable power development, especially that of intermittent sources such as wind and solar, has taken place at an unprecedented rate in many places around the world over the past decade. Four important attributes of (grid-connected) wind and solar capacity set them apart from their conventional fossil-based power generation counterparts:

- Renewable energy plants have to be located where the energy source is (sun, water, or wind), unlike thermal plants, which are easier to locate close to consumption centers.[3]

- Since the time required to build wind and solar plants is typically one-third, if not less, of a conventional power generation and transmission project, it is critical that the rest of the power system be ready before those resources start getting harnessed at a rapid pace.
- Wind (~35 percent average capacity factor) and solar (~18 percent average capacity factor) have much lower capacity utilization limits and higher costs per unit of capacity compared with their conventional counterparts (for example, ~80 percent for a baseload plant). Consequently, the up-front investment needed for an equivalent amount of generation (megawatt-hours) is typically three to four times higher for intermittent renewable generation than for typical thermal plants. As a result, fewer resources are available to invest in nonrenewable generation and transmission projects, albeit the near zero operating costs in wind-based and solar-based generation reduce the need for operating capital.
- Wind and solar have intraday, seasonal, and interannual variability—which means that the rest of the generation, as well as the transmission system, needs significant excess capacity. That implies higher investments without necessarily increasing the system's generation potential. It also makes it desirable to integrate energy markets over the largest scale possible—so as to be able to tap a large pool of baseload plants and access regions with different wind, sun, and hydrological conditions.

Although these seem like basic facts that should be folded into policy developments, the novelty of large-scale renewable means that they have not always been considered (Box 5.3).

Although some infrastructure services and investments do respond to market and price incentives, an estimated 60 percent to 80 percent of developing-country infrastructure investments are still in the hands of the public sector, which has a different incentive structure. Infrastructure decisions are often driven by concerns other than economic ones (say, a desire to integrate the country through a transport network or to promote the development of lagging regions). As a result, one cannot expect a carbon price to automatically translate into the required changes in infrastructure investments and technologies, and specific policies may be required.

The use of shadow carbon pricing can help reorient investment decisions, although the correct value to use is the subject of debate. Those governments, firms, and institutions that have adopted a shadow price for carbon typically have used values ranging between $20 and $60 in 2015, with central figures usually around $25 to $40 (figure 5.2) and increasing over time. The World Bank Group introduced a similar shadow price for use in its project assessments (World Bank 2014a). But although a shadow price is useful, the decision to invest in the kind of low-carbon infrastructure or to follow more efficient land-use planning will be driven mostly by policy priorities—whether about the climate or local and immediate benefits, such as lower pollution and congestion.

## BOX 5.3 Orchestrating Renewable Power Scale-Up—The Case of India and Australia

Renewable-based power generation is essential for reducing emissions to near zero levels in the long term. It also provides major benefits by reducing both atmospheric pollution and reliance on fossil fuel. However, experience with efforts to boost the share of renewal energy highlights the need for first carefully laying the groundwork—as illustrated in the following two country cases.

**Not Enough Preparation in India**

Over the past decade, India has embarked on a number of ambitious wind and solar expansion plans. As a result, total wind and solar grid-connected capacity of 25 gigawatts reached 10 percent of total installed capacity in October 2014, from a near zero base 10 years before. The bulk of that investment—about 7.4 gigawatts of wind power—occurred in the southern state of Tamil Nadu thanks to private developers. That development has many positive aspects, including less reliance on the state's 10 gigawatts of the coal and gas generator fleet. However, it has come at an expense. The baseload generation and transmission line development in Tamil Nadu took a backseat for the better part of the past decade, because most of the funding was channeled into lucrative wind deals.

As a result, close to 1,000 megawatts of wind capacity were effectively off grid in 2012, and the lack of backup generation capacity led to a massive 33 percent peak and energy deficit in the state in 2010/11 (Chattopadhyay 2014). Not surprisingly, under these circumstances, since 2013, there has been a shift to reduce incentives for wind power development and a renewed focus on bolstering backup generation and transmission investment. Better foresight in policy development and power system planning could have minimized those negative impacts of an unplanned growth in renewables.

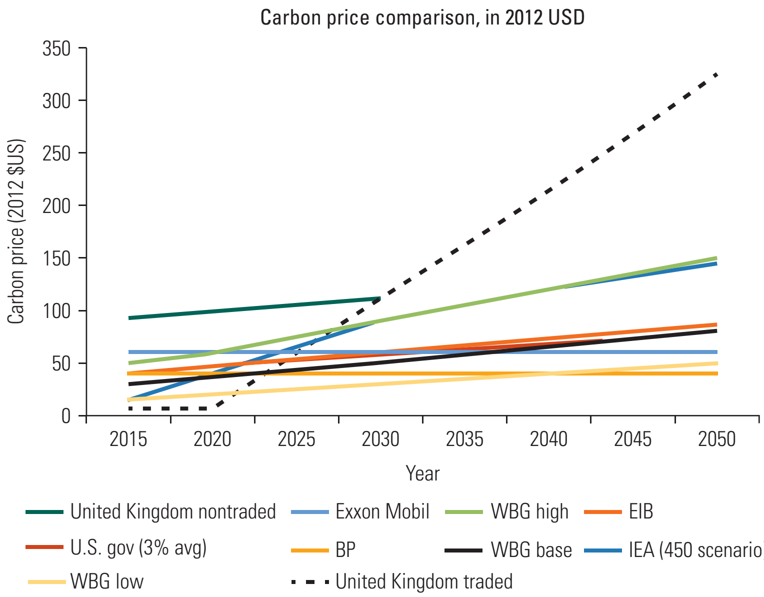
**Careful Preparation in Australia**

In contrast, the benefits of a carefully planned transition to a low-carbon state are visible in Australia—a country that is endowed with abundant solar and wind resources and that has been under considerable pressure from the international community to reduce its reliance on coal for power generation.

Australia started out slowly in the 1990s with a renewable energy target of about 5 percent of total electricity in 2010 and 20 percent by 2020. A significant parallel effort was under way to promote gas-based generation, in part to improve the diversity and flexibility of the generation system. That effort showed a remarkable degree of foresight and resulted in Australia's enjoying a significant generation capacity reserve margin. A new Scale Efficient Network Extension mechanism was also explored to support developing transmission lines to connect major wind hubs (AEMC 2011). Even so, the rapid expansion of wind has run into minor problems (such as greater congestion and difficulty in managing some of the lignite-based baseload capacity). New transmission projects are being developed to create much stronger interconnections across the states, thereby facilitating both new generation development and the management of the existing fleet of coal generation.

*This box was contributed by Deb Chattopadhyay.*

**FIGURE 5.2 Institutions with a Shadow Carbon Price Use a Range of Value That Increases over Time**




*Source:* World Bank (2014a).
*Note:* EIB = European Investment Bank; IEA = International Energy Agency; WBG = World Bank Group.

## Tackling Other Factors—Such as Behavior—That Reduce the Impact of Price Incentives

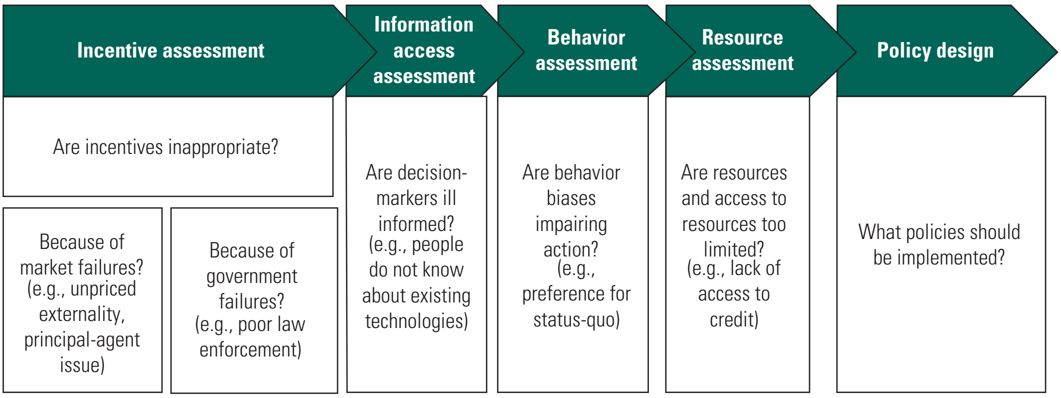
Economies of scale, incomplete information, and lack of infrastructure are all arguments used to advocate policies that will boost demand for low-carbon solutions and enable them to be quickly scaled up and their costs reduced. But there may well be other types of market failures and behavioral obstacles to their quick deployment. Figure 5.3 summarizes some of the obstacles that may require specific actions.

### Incentives

The first question is whether individuals and firms face the right incentives. Of course, incentives are distorted in the presence of subsidies for fossil fuels and in the absence of pricing of the climate externality. But bad incentives can also be due to other market or government failures. For example, a common market failure is what is known as the principal-agent problem—landlords who are reluctant to invest in energy efficiency if the tenant pays the heating bill, or employees who ignore energy-efficiency measures because their employer pays the energy bill.

As to government failures, many countries have enacted energy-efficiency requirements for new buildings without implementing measures to enforce them.

**FIGURE 5.3 How to Assess the Obstacles to Low-Carbon Solutions**




*Source:* Adapted from World Bank (2013).

Where regulations exist but are not enforced, better law enforcement can be an effective and low-cost strategy. In Brazil, enforcing existing laws caused deforestation to drop by 70 percent between 2005 and 2013 (Nepstad et al. 2014). That was accomplished by requiring landholders to submit their property boundaries and enabling government agencies to use satellite data, while expanding field operations and visibly applying fines and penalties (Assunção, Gandour, and Rocha 2013). Programs, such as REDD+ can be an important transitional tool to strengthen institutional capacities and reforms for better law enforcement.

Effective monitoring, verification, and reporting mechanisms are needed for better enforcement of laws, regulations, and pricing instruments. However, establishing such mechanisms is difficult in all sectors. For instance, verifying that new or retrofitted constructions are compliant with building energy-efficiency regulations is difficult and may explain the reluctance of homeowners to invest more. It has also proved extremely challenging in land-use sectors in developing countries, where a large number of generally very heterogeneous and dispersed land users in remote areas are involved. Relying on local communities for monitoring could reduce implementation costs and increase local ownership (Danielsen et al. 2011; Larrazábal et al. 2012; Palmer Fry 2011). The use of new technologies for data collection, such as low-cost satellite imagery, cloud computing, and mobile phones provides low-cost opportunities for better enforcement of existing regulation at low costs.

## Information

If incentives are correct, a second issue has to do with the availability of information and how individuals process it. Information may not be available about the energy efficiency of a product. Or it may be that individuals tend to rely on simple rules of thumb rather than carefully processing the available information. Hence, information disclosure efforts are often seen as a key step toward getting individuals to adopt more socially desirable behaviors ("if only they knew …"). For instance, energy-efficiency labels for appliances exist in some 40 countries worldwide (CLASP 2015). Those labels provide information, such as electricity consumption, in kilowatt-hours per year, that is expected from a refrigerator or a particular dwelling, and are sometimes complemented with estimated expenses from energy consumption. Forest certification programs (such as through the Forest Stewardship Council or the Rainforest Alliance) have been established for the environmentally friendly production of forest products. Similarly, multistakeholder *roundtables*—such as for palm oil, soybeans, sugarcane and sugar-cane ethanol, biofuels, and beef—have helped develop performance standards and principles for sourcing major commodities from deforestation-free sustainable practices (Nepstad et al. 2013).

The record of information disclosure programs is mixed, although they are effective if done well (Davis and Metcalf 2014; Kallbekken, Sælen, and Hermansen 2013; Nepstad et al. 2014; World Bank 2014b). Some labeling reports information that is too abstract, too vague, or too difficult to understand. Thus, the kilometers-per-gallon or miles-per-gallon measure used to evaluate vehicle fuel efficiency has been found to lead people to undervalue the fuel and cost savings of replacing inefficient vehicles (Larrick and Soll 2008). In fact, better labeling, focused on estimated lifetime costs, has been found to lead to better choices (Davis and Metcalf 2014). How the information is presented (in novel or vivid ways) is also important, given people's limited attention span (Sunstein 2013).

## Behavior

But even if information is available, individuals do not necessarily behave according to economic theory. *World Development Report 2015* (World Bank 2014b) is devoted to this topic, with a chapter on how behavioral issues contribute to the climate change challenge. The following are a few of the key issues:

- Evidence abounds about people being *tempted* by the low price of a refrigerator (Tsvetanov and Segerson 2014) or being inconsistent in their treatment of time (Ainslie 1975). The implication is that even with good information, people may not purchase a cost-effective energy-efficient appliance.
- People are easily influenced by social norms. The often-quoted experience of the U.S. Opower energy conservation program—in which home energy reports were mailed to residential utility customers, providing them with feedback on how their own energy use compared with that of their neighbors—illustrates the strengths and limitations of the use of social norms in energy conservation programs (Allcott 2011). The effect was shown to be strong—with energy consumption reduced by 2 percent, equivalent to an increase in electricity prices of about

11–20 percent—but to decrease rapidly over time. However, as the experience was repeated, new habits were formed, with homeowners investing in new appliances or developing new consumption habits (Allcott and Rogers 2014). That said, social norms programs need to be used carefully, so they do not backfire and result in high energy savers, reducing their efforts to bring their consumption down to that of their peer group's average.

- People tend to stick with the default option, which is why many energy companies are now setting the default program for consumers to be the greener but more expensive tariff, which consumers can opt out of. In southern Germany, the energy company Energiedienst GmbH found that 94 percent of its customers stayed with the default green option, whereas only 4 percent switched to a cheaper one, 1 percent switched to a more expensive greener one, and 1 percent switched to another supplier (Pichert and Katsikopoulos 2008).

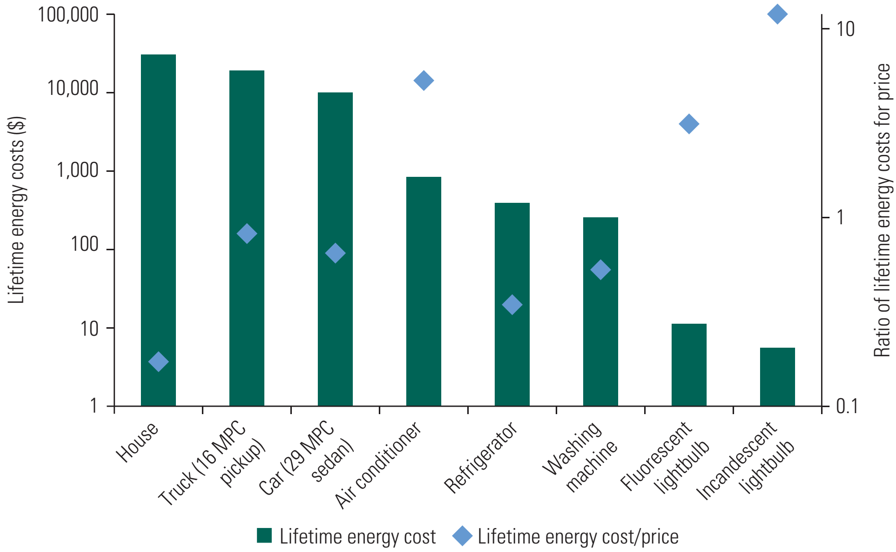
A critical challenge has to do with the *salience*—that is, the importance or the visibility—of the issue. Thus, firms for which energy costs are a small share of overall costs—or wealthy individuals for whom energy costs are a small share of their income—may choose not to devote attention to what is a small issue calling on their limited time and attention span. Thus, it appears as if business investments in energy efficiency in member countries of the Organisation for Economic Co-operation and Development require rates of return substantially higher than for investments with comparable risks (Center for Sustainable Energy [2012] as cited in World Bank [2014b]). More generally, the smaller the energy cost of a product relative to its purchase price, the more likely it is that consumers will not include energy-efficiency issues in their choice of appliance or technology (Sallee 2013). For example, as figure 5.4 shows, the relatively high lifetime energy costs of air conditioners and incandescent lightbulbs (compared with their price) stand out more than the case of a typical refrigerator, meaning that pricing solutions are more likely to be effective on the former than on the later (Allcott and Greenstone 2012).

Further, producers may not offer innovations that could pay for themselves, because they are not visible (hence, salient) to the consumers. A case in point is the automobile sector, where more cost-effective, but invisible-to-consumer efficiency improvements (such as low-friction lubricants, engine friction reduction, and variable valve timing) are not implemented, but far less cost-effective deployments (advanced diesel engines and turbocharging) are (Sallee 2013).

## Financial Resources

A final obstacle is the challenge of accessing the financial resources required to act. Most green or energy-efficiency improvements require an up-front additional cost that is expected to generate a flow of savings, but coming up with the needed finance will be tough for firms and individuals that are credit constrained. This topic is discussed in the next chapter.

**FIGURE 5.4** **What Matters Is the Relative Lifetime Energy Cost**




*Source:* Allcott and Greenstone (2012).

## Notes

1. This problem is compounded by information asymmetry in capital markets: competitive innovative projects often struggle to find the necessary funding, because investors lack the knowledge and information needed to assess the quality of innovative and risky projects, especially when technical details cannot be shared by the developers without risking competitors' reproducing their innovation.
2. Overcapacity led to a drop in prices that was even larger than the production-cost reduction.
3. Note that transport costs create an incentive to build power plants close to infrastructure or fuel extraction locations, especially for lignite, which is very expensive to transport.

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# 6. Getting the Finance Flowing

- A low-carbon transition requires increased long-term finance flows to developing countries and a bigger share allocated to low-carbon investments. As such, dedicated green finance is helpful but not enough.
- Obstacles to attracting long-term finance need to be tackled by improving the investment climate, growing local financial markets, building a pipeline of bankable projects, and reforming global finance to reduce the short-term bias of capital markets.
- Increasing the green share of the pie requires steps both to increase returns thanks to lower costs for low-carbon projects and to improve risk perception.

Getting prices right and developing climate policy packages will increase demand for low-carbon investment, in both public goods (such as mass transport infrastructure) and private goods (such as factories' energy-efficient machinery or firms' and households' building improvements). But firms, governments, and households are unlikely to find their own savings sufficient and will require access to external financing sources.

Analysts agree that the additional investments needed for a low-carbon economy are modest compared with total investment levels. The Intergovernmental Panel on Climate Change estimates that reaching the 2°C target would require additional investments of about $400 billion per year. Similarly, the New Climate Economy's report (NCE 2014) estimates an additional $300 billion will be needed, compared with baseline investment needs of $4 billion per year over the next 15 years.

However, those requirements will come on top of existing unsatisfied financing needs. Firms and households in developing countries are chronically credit constrained. Governments in both developed and developing countries already struggle to finance infrastructure. Thus, the bulk of the financial flows for the low-carbon transition will have to come from the private sector—but with assistance from public money and regulatory reforms. Addressing the finance gap entails looking at banking and financial regulations and how they can be used to make long-term investments more attractive for investors and intermediaries. The recent financial crisis, combined with growing awareness of the increasing divergence between the needs of society and the performance of financial markets, is resulting in calls for deep reforms in financial markets and banking regulation—reforms that can reduce market power and opaque operations so that assets and basic risks can be properly valued.

Low-carbon projects present a mix of challenges in attracting financing. Some are standard and have to do with the generic challenges of attracting finance to developing countries and to long-term investments such as infrastructure. Others are specific to low-carbon investments—which tend to be more capital intensive, may involve newer technologies, carry more policy risks, or simply require doing things differently. Hence, the key message of this chapter is that reforms are needed to increase both the financing available to long-term projects in developing countries—to grow the pie—and the share of financing apportioned to low-carbon investments—to green the pie.

## Growing the Pie

The challenge of the low-carbon transition starts with tackling the chronic lack of financing for productive investments that plagues most developing countries and the need to find new sources of financing and to leverage existing ones.

### The Long-Standing Challenge of Increasing Financing for Long-Term Projects and for Developing Countries

Infrastructure does not attract enough capital, especially in developing countries. Long-term, less liquid investments are not perceived as attractive by global capital, especially in developing countries. Consequently, developing countries struggle to finance the infrastructure and private sector development they need to grow and prosper.

Many countries are simply too poor to generate the needed pool of savings domestically. Many others lack local capital markets that are sufficiently developed to transform local liquidity into the patient capital that is needed for longer-term investments. Maturities are also significantly shorter for sovereign bonds in developing countries, increasing their exposure to changing economic conditions and raising risks from projects with long-term returns (Borensztein et al. 2005).

Further, public spending is limited by a low tax base (10–20 percent of gross domestic product in many countries) and debt ceilings. Overseas development assistance can play a catalytic role in mobilizing additional resources. But it is constrained by the donor's own fiscal constraints and remains limited relative to overall needs—at its highest around 2011, it reached about $90 billion.

There is no question that infrastructure spending needs scaling up (box 6.1). But it also needs derisking so as to generate a steady, long-term rate of return attractive to the private sector. Green or not, infrastructure requires sinking very large sums of money into largely illiquid assets. Investments are typically lumpy even as they generate flows of services over long periods. Some can be managed to generate income flows (such as

### BOX 6.1 Infrastructure Investment Needs Illustrate the Challenges Faced in Securing Long-Term Financing in Developing Countries

Millions of people in developing countries still lack access to safe water, improved sanitation, electricity, and transport. Even disregarding climate concerns, developing countries need substantially more infrastructure to grow and address poverty, inequality, and unemployment concerns.

Little data exist on how much is being spent on infrastructure, and how much should in fact be spent—except in Africa, where a concerted, multiyear effort was undertaken to collect that information (Foster and Briceño-Garmendia 2010). Also, estimations of needs depend on countries' objectives—providing basic services to the population or investing in state-of-the-art infrastructure for long-term growth.

A number of *guesstimates* of infrastructure requirements exist, which vary depending on the definition of needs and the countries they cover. The World Bank Group estimates that about $1 trillion per year would be needed in developing countries to start closing the infrastructure gap, with about $100 billion for Africa alone. But the costs are much higher if the goals are more ambitious. For example, by another estimate the BRICS (Brazil, Russia, India, China, and South Africa) alone could absorb $1 trillion per year to build the infrastructure needed to become high-income economies. And, of course, the numbers balloon if high-income countries are included. The New Climate Economy's report estimates that about $5.5 trillion per year will be needed in infrastructure globally by 2030 (NCE, 2014).

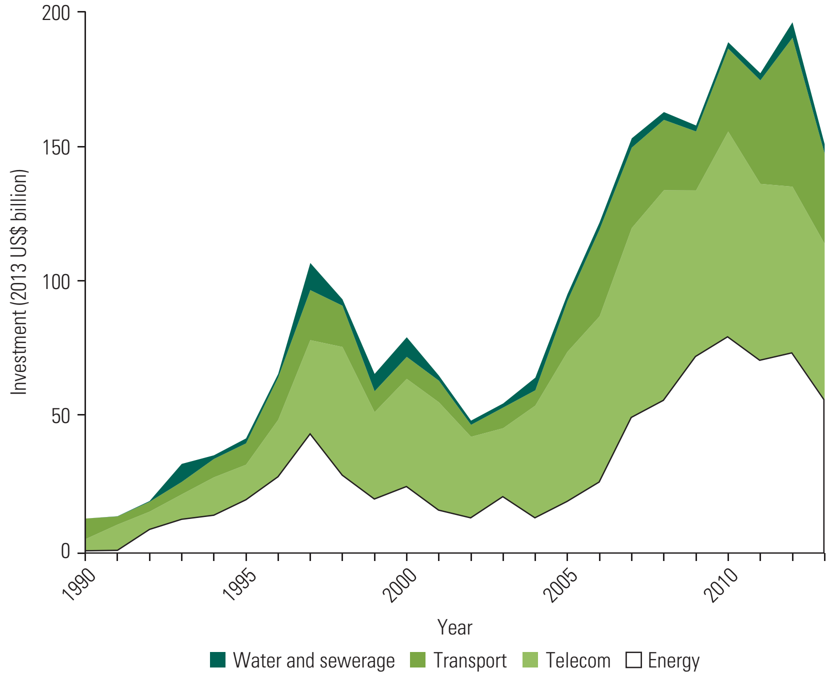
But regardless of the variations across estimates, all agree that developing countries underinvest in infrastructure—with the notable exception of China. Another guesstimate (this one from the World Bank) is that the developing world currently invests some $500 billion per year in infrastructure. Existing gaps in access to infrastructure are evidence to this underinvestment. Spending better and improving cost recovery would surely help reduce the gap, but more will still likely be needed. The study by Foster and Briceño-Garmendia (2010) showed that addressing these inefficiencies in Africa could reduce the funding gap by two-thirds—but cannot make it go away.

power plants, water and sanitation plants, high-traffic highways, ports and airports, public transportation, and telecommunications), whereas others struggle to do so (such as lower-traffic roads and electricity transmission lines). Furthermore, infrastructure is regulated by public entities, making it subject to significant regulatory risk.

Private participation in infrastructure may already be financing about 20–40 percent of total infrastructure investments and could theoretically be expanded. However, after nearly two decades of steady growth, private participation in infrastructure seems to have slowed down and has hovered between $150 billion and $200 billion over the past seven years (figure 6.1).

Most countries are constrained by a limited pipeline of bankable projects for private investment (leading experts to complain about "too much money chasing too few bankable projects") and not enough resources to prepare projects and develop a robust project pipeline. Many countries struggle to develop the expertise to negotiate financing terms, to access nontraditional financing without overloading national debt

**FIGURE 6.1 After Two Decades of Growth, Private Infrastructure Investments in Developing Countries Seem to Have Plateaued**



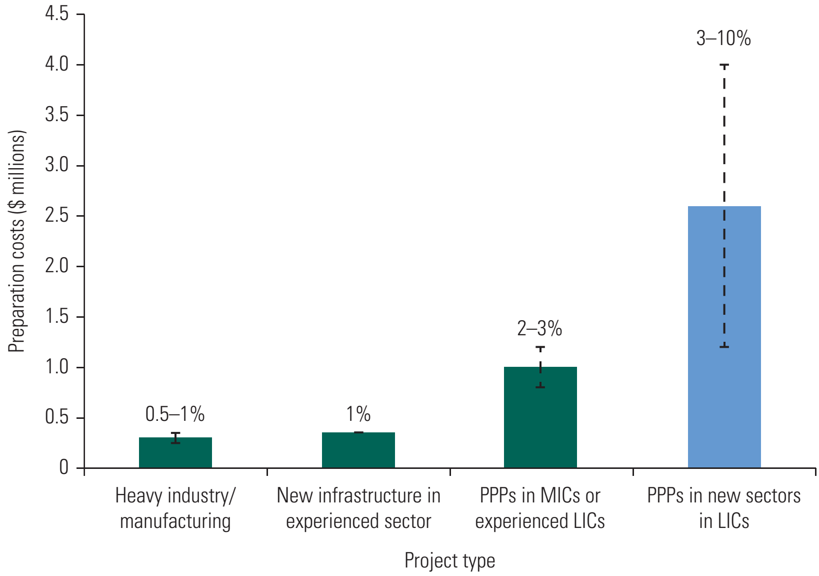

*Source:* World Bank Private Participation in Infrastructure database (http://PPI.worldbank.org).

burdens, and to evaluate projects on multiple criteria (including value for money, financial viability, affordability, and sustainability).

Moreover, project preparation is costly: the legal and engineering studies for a repeat and fairly simple project will amount to only 1 percent of project costs, but it can reach 2–3 percent for new sectors in middle-income countries and 3–10 percent for new sectors in low-income countries (figure 6.2). And although a number of project preparation facilities exist (mostly in Africa), they tend to be small and lack sufficient expertise.[1] Grant sizes rarely exceed $10 million and in most cases are less than $1 million.

In developing countries, access to finance is a problem not only for infrastructure but also for households and firms. Although capital markets are emerging that allow for local-currency trading, they remain concentrated in a few countries. Moreover, local markets tend to focus on government bond markets, leaving corporate bonds and other financial assets aside. Banks tend to prefer to lend against assets (as for mortgages) or to buy government bonds. Access to finance is particularly problematic for small and medium-size enterprises, which typically lack transparency, tangible assets, and records often because of informality. World Bank Group estimates suggest that the unmet credit needs of formal small and medium-size enterprises amount to nearly $1 trillion—and

**FIGURE 6.2 Project Preparation Costs Can Sharply Increase the Overall Tab**
*(Typical preparation costs for medium-size [$40 million] infrastructure projects)*




*Source:* IFC data.
*Note:* LIC = low-income country; MIC = middle-income country; PPP = public-private partnership.

that amount more than doubles to between $2.1 trillion and $2.5 trillion if microenterprises and informal businesses are included (Stein, Goland, and Schiff 2010).

## Finding New Financing and Leveraging Existing Sources

So where can the needed financing come from? Recommendations typically fall into two broad categories: steps to make the investments more attractive and steps to leverage and make the most of available capital.

Making investments more attractive starts with improving the investment climate. Investments will go where regulations are clear and predictable, the rule of law and property rights are enforced, inflation is low, and growth is high, or at the very least where economic prospects are good.

In addition, the lack of a good project pipeline for private investments has led to a new focus on making resources available for project preparation. Thus, new financing facilities such as the World Bank's Global Infrastructure Facility will make dedicated funds available for preparation. More generally, the lack of a good pipeline calls for using concessionary financing to help prepare projects in a way that enables countries to attract more private financing and to increase the quality of the public-private partnership projects they engage in.

Making the most of available capital starts with improving the role and dynamism of local financial markets. Local banks, pension funds, and capital markets offer a number of advantages if they can be tapped. Those investors have a better knowledge of local conditions, making them much better investors for politically complex projects, such as those in the water sector. Further, local finance mitigates foreign-exchange risk, provides opportunities for reforming and enhancing local financial markets, creates additional opportunities for local banks and investors, and unlocks long-term liquidity in those financial markets.

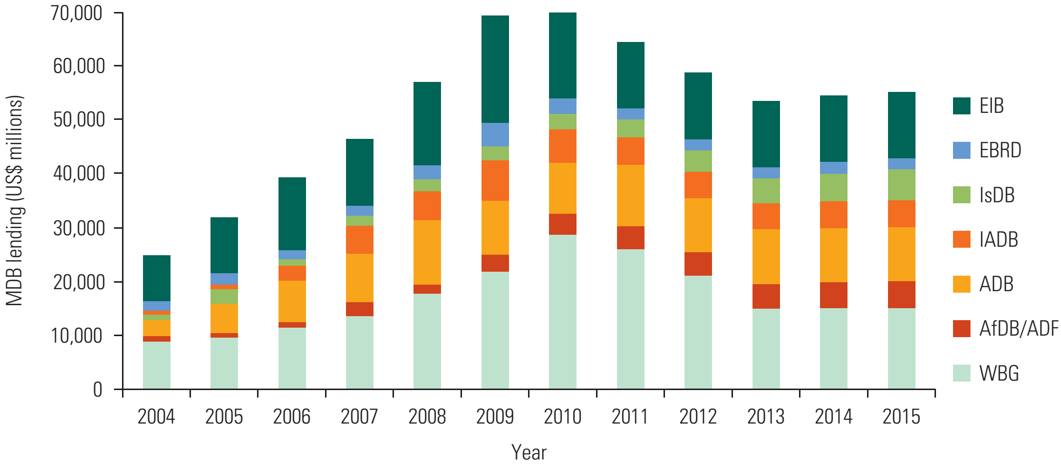
But efforts are needed to ensure that developing countries have the means to transform local liquidity into tenders of debt for a 12-year to 18-year range or longer. Governments have experimented with various models, each with its own challenges, strengths, and weaknesses. Some have relied on a financial intermediary such as a national development bank, for example, the Brazilian National Bank for Economic and Social Development. Others have opted to intervene directly in market creation, as in the case of Fonadin in Mexico. Such actions leverage the government's credit position, allowing access to lines of credit and capital markets that a private entity might not have. However, public entities are generally subject to public employment rules and may not be able to pay the salaries needed to compete with financial markets to attract the best talent. They are also vulnerable to political influence as to which projects they finance and how decisions are made. Subject to public oversight, they may have limited capacity to rapidly respond to market demand.

Institutional capacity also needs to be built within local (and city) governments to lay the foundations for coordinating with the private sector and leveraging land-backed instruments for infrastructure financing. The Public-Private Infrastructure Advisory Facility, for instance, helps build the capacity of city government officials to prepare and enter into public-private partnership arrangements with private partners (such as with reforms to institutions, policies, and legal and regulatory frameworks). The Public-Private Infrastructure Advisory Facility's goal is to provide local governments with market-based finance (such as municipal bonds or bank loans) without sovereign guarantees to improve their ability to finance urban development.

Other actors include the multilateral development banks (MDBs) and bilateral development banks, which provide advisory services to help countries develop strong capital markets and channel official development assistance. Although these additional financial resources are small relative to the need—MDB lending for infrastructure peaked at about $70 billion in 2010 (figure 6.3)—they are critical in the poorest countries, where they often fund a substantial share of infrastructure investments. MDBs can have a significant impact if they are leveraged to make investments more attractive to the private sector.

Recent years have seen increasing calls, especially from the large middle-income countries, for increasing both the capital base of MDBs and their ability to leverage

**FIGURE 6.3 Multilateral Development Bank Lending for Infrastructure Peaked in 2010**
*(Recent and projected MDB lending for infrastructure)*




*Source:* MDB Working Group on Infrastructure.

*Note:* No projections were provided for EBRD and EIB; hence, it was assumed that lending would revert to precrisis (2007) levels. ADB = Asian Development Bank; AfDB/ADF = African Development Bank/African Development Fund; EBRD = European Bank for Reconstruction and Development; EIB = European Investment Bank; IADB = Inter-American Development Bank; IsDB = Islamic Development Bank; MDB = Multilateral Development Bank; WBG = World Bank Group.

their resources—either through a more aggressive use of their capital base or through a greater focus on cofinancing projects that bring in external financing.

But this has proved challenging. In recent years, the equity-to-loan ratio of the World Bank's International Bank for Reconstruction and Development has improved from about 30 percent in 2009 to about 25 percent in 2014, enabling it to finance $156 billion in outstanding loans for $40 billion in usable equity. However, considering the current equity-to-loan ratio, appropriate risk limits, and the maximum gearing ratio of 1 to 1 between outstanding loans and subscribed reserves (including call-in capital that amounts to $233 billion), the current capital base cannot provide an increase in lending of the order of magnitude required to finance the needs for infrastructure development.

Other MDBs may have more room to increase their lending envelope, and MDB recapitalization is also an option, but while useful, these options cannot alone close the current financing gap. Private capital is necessary in all scenarios, and making the most out of MDB resources requires leveraging them to attract private resources, for instance, through derisking projects with guarantees and blended financial instruments.

Finally, large middle-income countries—notably Brazil, China, and India—are playing an increasingly important role, particularly in Africa, where their annual commitments rose to nearly $10 billion in 2010. China's spending has contributed to Africa's power generation, helping install 9 gigawatts of additional capacity, including 10 major hydropower projects. Other emerging economies have also taken an active interest in African infrastructure financing during the past decade. On average, India invested $1.2 billion and the Arab states $1.5 billion from 2005 to 2009. But unlike traditional official development assistance, this new financial assistance is provided on the basis of mutual benefits and reciprocity, and is rooted in bilateral agreements. China and India generally do not channel their official development assistance through a development agency, but rather through their export-import banks, which have an explicit trade promotion objective.

Regardless of progress in using existing instruments to increase financing for long-term investments in developing countries, there is a growing recognition that marginal changes may not be enough to close the gap in development finance, especially in lower-income environments. A holistic approach may be needed to align the financial system toward longer-term sustainable development. That will be key to delivering the long-term economy-wide transformation to greener growth and to mobilizing domestic investors to deliver on both countries' development and climate objectives.

Aligning the financial system to development needs would require a shift in its focus toward longer-term profitability. Indeed, there is evidence that financial markets have a short-term bias and place too much emphasis on short-term earnings (Black and Fraser 2002; Bushee 2001; Miles 1993). That bias can be explained in part by the way compensation schemes are designed (Tehranian and Waegelein 1985), and by herd behavior (Bikhchandani and Sharma 2000) and other imperfections in capital markets, such as credit constraints and arbitrage costs (Shleifer and Vishny 1990). It leads to chronic underinvestment in long-term projects.

Even regulators of the financial sector usually focus on short periods. For instance, in 2011, U.S. supervisors began integrating coordinated stress testing into the supervision of large banks and bank holding companies with the Comprehensive Capital Analysis and Review—a supervisory program to assess large banking companies' internal capital planning processes and capital positions—and the Dodd-Frank Act Stress Testing. Those two stress tests use scenarios with time horizons of nine quarters, a little more than two years (Hirtle and Lehnert 2014). Although obviously relevant for macroeconomic risks, those assessments of the robustness of the financial system do not say anything about long-term risks, such as *stranded* assets (assets rendered prematurely obsolete because of greener needs; see chapters 2 and 8) or climate change impacts.

## Greening the Pie

In addition to growing the financial pie, decarbonization will entail allocating a larger share to low-carbon investments. A lack of available financing for infrastructure has led countries to invest in the options with lowest up-front costs—which are often the most polluting. Solving global capital market issues will help promote higher-quality and cleaner infrastructure in developing countries. But low-carbon investments also present a number of additional challenges that decrease their risk-adjusted returns compared with conventional investments and require specific solutions.

## The Specific Challenges of Low-Carbon Projects

***Higher up-front costs.*** Initial investments for green projects are a higher proportion of total costs than in conventional projects (such as renewable electricity production compared with thermal power plants), making projects even more sensitive to the finance cost. It is therefore critical to reduce the risks of green infrastructure. It should be noted that being more capital intensive need not mean being more expensive, as the additional up-front capital cost can be partly or fully offset by the savings generated through lower operating expenses. Thus, an initial investment in energy efficiency can be partially or fully recouped by subsequent reductions in fuel costs. And although solar and wind power plants typically are much more expensive to build than thermal power plants, they operate at practically zero cost. Nevertheless, a higher up-front capital cost increases both the need for up-front capital and sensitivity to financing costs.

***Higher technology risks.*** Higher technology risks occur simply because the underlying technologies are newer and are still being innovated, with anticipated rapid declines in costs in the future. Consequently, a particular fear of investors is to develop a cost disadvantage by moving too early and having to compete with later-generation technology that is cheaper, more reliable, or both.

***Higher regulatory risks.*** To reduce the previously mentioned risks, some governments have provided subsidies (such as feed-in tariffs for renewables) to green power technologies since the early 1990s. But given the high cost and long-term commitments, a number of countries (most notably Spain, but also Bulgaria, the Czech Republic, and Romania) have reversed earlier commitments and reduced their feed-in tariff, resulting in a drop in investments (Bloomberg New Energy Finance 2014). With green technologies still largely reliant on government subsidies, policy reversals create uncertainty among investors as to whether they will recoup their initial investments.

***Different risk perceptions.*** Low-carbon projects require project financiers and developers to innovate and think differently relative to the standard deals they would have made even 10 years ago. This is a challenge, given the tendency of individuals to stick to the default option and to prefer the status quo—and thus to keep doing the same thing (Weber and Johnson 2011; Weber, Lindemann, and Plessner 2008). China's experience shows that it takes considerable encouragement (credit lines and public support) to get commercial banks involved in a new area like energy efficiency (Wang et al. 2013). The general tendency to stay with the status quo may be the strongest argument in favor of dedicated green finance schemes, given the well-documented herd behaviors found in financial markets (Bikhchandani and Sharma 2000; Chari and Kehoe 2004; Devenow and Welch 1996). To attract significant resources, green investments need to become mainstream.

The combination of higher up-front costs and higher risks decreases the risk-adjusted return of low-carbon projects compared with conventional ones. Previous chapters of this report have discussed the many instruments that can make green investments more attractive by increasing their returns compared with brown projects—such as carbon prices, feed-in tariffs or standards and regulation. Here, we focus on instruments that rebalance risk perception between low-carbon and brown projects, and tools that increase the risk-adjusted returns of green projects.

## Rebalancing Risk Perception

A crucial step in the transition toward low-carbon financing is to mainstream low-carbon projects and change expectations about future policies to bring the perceived risks of green and brown projects closer to their fundamental values.

First, the international community, governments, and local actors can pave the way by sending a clear signal that they are committed to trigger a transition toward a carbon-neutral world (see chapter 1). The best place to do so would be the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change—to be held in Paris in December 2015. It would mean convincing all economic actors that the future is carbon neutral, along with designing an international architecture to support climate change mitigation (including financial instruments).

Doing so would be the most powerful instrument for redirecting investments. It would help with risk perception and the fear of policy reversal. It would make it easier to finance green projects, especially those with a long lifetime. It would also support the long-term credibility of climate policies that is required to make firms invest in long-term projects; new, more efficient, products; and radical green research and development. Furthermore, it would help address the need for cross-sector coordination (for instance, among developers of electric cars, producers of batteries, and local authorities able to deploy recharge infrastructure). That contribution from the Paris meeting could be strengthened further by involving nongovernmental actors—such as cities, private firms, and investors. After all, the broader the coalition, the stronger the signal sent to the economic community, and the more likely the shift in investment patterns.

Second, financial actors need to be aware that the implementation of climate regulations—regardless of its perceived likelihood—would trigger a major shift in the profitability of various assets. Here, a key would be credit ratings, which play a critical role in resource allocation. Methodologies already exist to account for environmental risks in sovereign credit risk analysis (such as the United Nations Environment

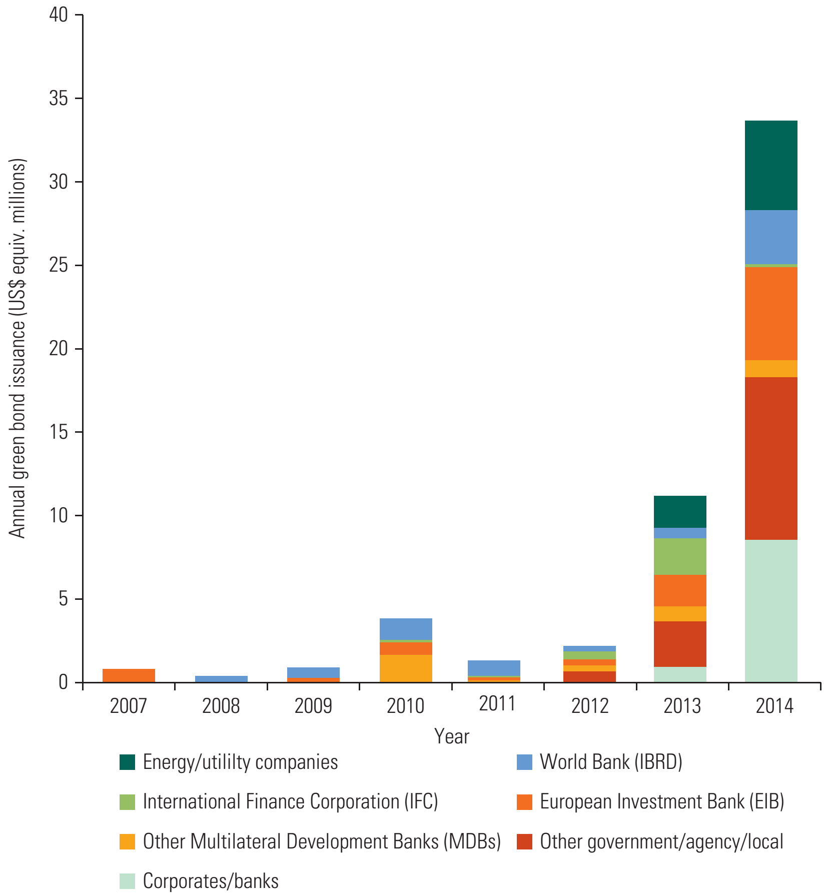
Programme Financial Initiative's E-RISC (Environmental Risk Integration in Sovereign Credit) analysis methodology), and some major rating agencies have started to include green considerations in their ratings (Inquiry 2015). If credit ratings include the risk that some assets may lose their value if climate mitigation policies are implemented, it could already redirect large flows of private capital from carbon-intensive assets to carbon-free assets, on the basis of the risk diversification argument alone. Recent investments of oil companies in renewable energy illustrate such a diversification strategy. A similar strategy could be recommended to countries that are exposed to carbon-pricing risks (such as fossil-fuel exporters) and countries that heavily rely on energy-intensive industries.

Third, a fundamental innovation being considered is extending stress testing of financial actors—that is, simulations of what would happen in the event of an equity markets crash, high unemployment, or other drivers of financial crisis—to take the long term into account (beyond the two years that are currently being looked at) and to include unconventional factors, such as climate policy (carbon exposure) and environmental constraints. In December 2014, the Bank of England agreed to examine for the first time the vulnerability that fossil-fuel assets could pose to the stability of the financial system in a carbon-constrained world. The results of that effort—combined with changes in investment patterns—could lead many investors to reconsider their perception of risks and investment decisions, resulting in increased flows to greener projects. Discussions on this topic are still at an early stage, but stress tests could evaluate the financial impacts of plausible environmental scenarios on assets, portfolios, institutions, and financial markets as a whole.

Fourth, green financial products such as green bonds are being used to help overcome the behavioral bias toward conventional investment. In 2014, the green bond market experienced exponential growth, reaching almost $35 billion in bond issuances, up from about $12 billion the year before (figure 6.4). Concurrently, guidelines set by the International Capital Markets Association—such as the Green Bond Principles—have been key to promoting the integrity of the green bond market by clarifying the issuance process. A further sign of momentum in the market has been the development of green bond indexes from such heavyweights as Bank of America, Merrill Lynch, Standard & Poor's, MSCI, and Barclays. Although the selection criteria are different for each of the existing indexes, they serve as tangible benchmarks that help the growing investor base assess the performance of this asset class.

Fifth, private actors are beginning to voluntarily decarbonize asset portfolios as a business strategy on the basis of diversification and long-term expectations regarding the future of energy. At the United Nations Climate Summit in September 2014, institutional investors committed to decarbonize $100 billion in institutional equity investments by the 21st Conference of the Parties in Paris and to measure and disclose the carbon footprint of at least $500 billion in investments, all while accelerating

**FIGURE 6.4 Annual Green Bond Issuances Are Up Dramatically**




*Source:* International Bank for Reconstruction and Development treasury.

*Note:* IFC has issued about $3.7 billion, and the World Bank (IBRD) has issued more than $7 billion in green bond transactions. EIB = European Investment Bank; IBRD = International Bank for Reconstruction and Development; IFC = International Finance Corporation; MDB = multilateral development bank.

investments in low-carbon assets. Commercial banks agreed to provide $30 billion in new climate finance by the end of 2015 by issuing green bonds and other innovative financing instruments. The insurance industry committed to double its green investments to $84 billion by the end of 2015 and to multiply them by a factor of 10 by 2020.

## Increasing Risk-Adjusted Returns for Low-Carbon Projects

The imbalance between green and brown projects is not just a perception issue. Where prices do not include the climate externality, low-carbon projects are most of the time less profitable. Measures are also needed that reduce the *actual* risk from green investments and that rebalance their costs and benefits.

### *Green Projects Can be Supported by Public Resources*

The financial costs of low-carbon investment can be reduced through direct government support, either by lending directly to low-carbon sectors or by backing low-carbon projects. Given the limited funds available in an era of shrinking government budgets, public finance is a short-term option that aims at leveraging private finance. Many tools are available. Green credit lines, which channel public money to low-carbon projects, use commercial banks as an intermediary—and typically, the private sector bank or financial institution provides additional cofinancing for the projects. Risk-sharing facilities—such as partial risk or partial credit guarantee programs—are established by a government agency or public financial institution to reduce the risk to the private sector of financing a green project (IEA 2011).

Importantly, domestic green public finance can be viewed as a way to increase the long-term credibility of other climate mitigation instruments and to reduce regulatory risk (as governments are perceived to have *skin in the game*). When such finance is used to back risky low-carbon projects, the government bears the loss in case of failure because of, for instance, a change in environmental regulation. The United Kingdom's Green Investment Bank has backed many projects, including offshore wind farms, bio-energy, and waste and energy efficiency, with capital costs ranging from £2 million to £1 billion. The Green Investment Bank has also set up five funds with £250 million to help attract private finance for small projects. In France, the Caisse des Dépôts et Consignations invests in low-carbon projects in cities and participates as a minority shareholder in the capital of low-carbon firms.

Internationally, the role of multilateral and bilateral development banks, as well as multilateral funds, will be central in leveraging private capital. The *Climate Investment Funds*—which hold more than $8 billion in resources and are expected to attract at least $57 billion in cofinancing—are investing in the energy, transport, and forestry sectors and in climate-resilient development in 63 developing countries. The *Green Climate Fund*, which recently reached its capitalization goal of a minimum of $10 billion, is in the process of designing a Private Sector Facility targeting private investors. It will provide catalytic first-loss capital guarantees to help smaller investments (such as off-grid solar lighting or clean cookstoves) or subordinated debt to enable financing for large-scale clean-energy infrastructure.

MDBs can also develop common metrics and analytical tools to help measure performance and to improve clarity on the financing purpose. Doing so will require innovation and experimentation, and a combination of many instruments and tools. Box 6.2 gives examples of innovative public finance ranging from China's Energy Efficiency Finance Program to the Pilot Auction Facility for Methane and Climate Change Mitigation. Box 6.3 provides a list of potential innovations proposed by the Global Innovation Lab for Climate Finance, which facilitates access to finance for low-carbon projects and reduces their risk, thereby lowering overall financial costs.

**BOX 6.2** **Innovative Public Finance at Work**

The International Finance Corporation (IFC) recently provided a $30 million loan to the *respons Ability Energy Access Fund*, which will provide working capital loans to manufacturers and distributors of solar LED lighting. Solar LED devices provide lighting as well as power for charging cell phones or small appliances, thereby supporting economic activity and better livelihoods. As such, they provide an affordable first step up the energy access ladder for the underserved with entry-level products costing $12–$20 per unit (paybacks as short as two to four months).

*Global Energy Efficiency and Renewable Energy Fund*. This fund is advised by the European Investment Bank Group and was launched in 2008 with funding of €112 million from the European Union, Germany, and Norway. It aims to anchor new private equity funds focusing on renewable energy and energy-efficiency projects in emerging markets and economies in transition (Africa, Asia, the Caribbean and Pacific region, non-EU Eastern Europe, and Latin America). In 2013, it welcomed its first private sector investors and by year-end had invested in six funds. The goal is to invest in up to 14 funds.

In China, IFC has worked with the Chinese banks on the *China Energy Efficiency Finance Program*, which provides loans worth $790 million and finances 226 projects that are slated to reduce emissions by 19 million tons of carbon dioxide per year. The program has enabled key players in China's economy—banks, utility companies, government agencies, and suppliers of energy-efficiency equipment and services—to collaborate in creating a sustainable financing model that will long outlive IFC's initial investment.

The World Bank Group and its partners recently launched the *Pilot Auction Facility for Methane and Climate Change Mitigation*, a pay-for-performance instrument that will use auctions to maximize the use of public resources for climate mitigation while leveraging private sector financing. It was approved in November with an initial $53 million in funding and will organize its first auction in the second quarter of 2015 (see World Bank [2014]).

Finally, financial guarantees against policy, regulatory, and macroeconomic risks can enhance the creditworthiness of public off-takers of green power and can encourage foreign and local commercial lenders to participate in projects via new players such as export credit agencies (Frisari et al. 2013).

### *Investments Can Also be Redirected through Regulation of the Financial System*

Giving commercial banks financial incentives to support greener projects can contribute to changing investment flows, even in the absence of a strong price signal. Commercial banks are the largest asset poolers worldwide and are the principal source of external finance for both small and medium-size enterprises and the emerging markets (Campiglio, forthcoming; Eickmeier, Gambacorta, and Hofmann 2013). Also, although financial markets reallocate the existing stock of credit, commercial banks are the only financial institutions, together with central banks, allowed to create new credit (McLeay, Radia, and Thomas 2014).

### BOX 6.3 Global Innovation Lab for Climate Finance's "Call for Ideas"

The Global Innovation Lab is a global initiative that supports the identification and piloting of cutting-edge climate finance instruments by bringing together private and public partners (development finance institutions, export credit agencies, and multilateral development banks). It aims to drive billions of dollars of private investment into climate change mitigation and adaptation in developing countries. In spring 2015, its principals are expected to endorse the top instruments and to weigh how and where the most promising ones could be piloted through Lab-backed public-private partnerships.

In 2014, an international *call for ideas* attracted more than 90 proposals, which were screened for actionability, innovativeness, and catalytic and transformative potential. The Lab is now focused on finalizing four of them:

**Agricultural supply chain adaptation facility**
The facility intends to tackle small to medium-size producers' and processors' inability to access medium- and long-term credit, as well as their information and capacity gaps. It will assume the first-loss position that multilateral development banks and other market-based lenders are unable or are unwilling to take, and it targets corporations' credit analysis and agricultural extension capacity gaps.

**Climate development and finance facility**
The facility combines fast-track project development support with better and timely capital for private sector climate mitigation projects. The target country group represents a significant market in which the proposal can reduce the complexity and delays in project development that emerge from development finance institutions and other investors' exposure limits to individual projects.

**Insurance for energy savings**
The proposal aims to effectively address technical and financial risks and to enhance access to financing energy-efficiency measures for small and medium-size enterprises in developing countries.

**Long-term currency swap**
The currency swap provides a practical solution to the problem of exchange-rate risk. This instrument could facilitate greater flows of foreign capital to developing countries, lower the cost of capital and improve debt tenors. The market for this instrument is very large and two experienced and suitable institutions are interested, although some implementation hurdles remain.

*Source:* Global Innovation Lab website, http://climatefinancelab.org/.

In many countries, banking regulators already use regulation to encourage or discourage bank lending activities, such as influencing which sectors to prioritize or which borrowers to favor (such as small and medium-size enterprises). Similar policies could be used to promote long-term or low-carbon projects (box 6.4).

In fact, many are already being implemented:

- In Lebanon, the National Energy Efficiency and Renewable Energy Action provides cheaper credit to the private sector for renewable energy and building energy-efficiency projects (Banque du Liban 2010; PWMSP 2011).

### BOX 6.4 A Toolkit of Banking Regulation Measures for Low-Carbon Finance

- *Refinancing*. Linking the quantity and prices of central bank refinancing operations to long-term sustainability factors (such as dedicated credit lines for low-carbon and green investments at discounted interest rates).
- *Fractional reserve banking*. In countries where banks have sizable binding reserve requirements, increasing the bank's mandatory reserves in the central bank in exchange for new loans targeted at low-carbon projects. Specific proposals include creating *carbon certificates* that a bank would get in exchange for financing an abatement project and that would act as legal reserves (Rozenberg et al. 2013).
- *Basel requirements*. Extending Basel III rules—a comprehensive set of measures developed by the Basel Committee on Banking Supervision—to allow lower capital or liquidity requirements for low-carbon projects.
- *Liquidity operations*. Updating the definitions of what can be considered as collateral in repurchase agreements to include green assets.
- *Balance sheet management*. Mainstreaming environmental and social factors in the routine management of assets on central bank balance sheets from a risk and asset allocation perspective (including in pooled asset management services offered by the Bank for International Settlements and the World Bank).
- *Quantitative easing*. Integrating environmental and social factors into special asset purchase programs, including the purchase of green bonds. In the Euro Area, proposals have been made for the European Central Bank to purchase €1 trillion in new bonds from the European Investment Bank to fund infrastructure projects as a way of escaping deflation.
- *Transparency*. Extending central bank reporting on monetary policy to reflect social and environmental impacts and dimensions.

Internationally, there are proposals for deploying special drawing rights, the international reserve asset created by the International Monetary Fund, to finance climate action and sustainable development more broadly, flowing from the IMF's Article XVIII, which authorizes a new special drawing rights allocation to meet "the long-term global need."

*Source:* Adapted from Inquiry (2015).

If a commercial bank endorses a loan request, the technical proposal is then assessed by the Lebanese Center for Energy Conservation, an agency affiliated with the Lebanese Ministry of Energy and Water. If approved, the Lebanese Central Bank provides its support by reducing the bank's obligatory reserve requirements by an amount equal to 100–150 percent of the loan.[2]

- In Bangladesh, the central bank is promoting sustainability, growth, and financial stability simultaneously through the following measures: (a) concessional refinancing for commercial banks at reduced interest rates for loans given in priority areas, such as renewable energy; and (b) requiring financial institutions to allocate a share of their loan portfolios to agriculture, a key climate-affected sector (Inquiry 2014).

- In Brazil, the central bank regulates environmental and social risk management for banks and monitors financial resources allocated to the green economy. At this point, 12 percent of bank lending and 62 percent of assets under management in the pension system are now covered by policies that require sustainability assessments (Inquiry 2014).

The bottom line is that monetary policies in favor of low-carbon projects can be a temporary alternative to carbon pricing (Rozenberg et al. 2013). They can also complement other climate mitigation policies when banks are hesitant or uninterested in new low-carbon investments. But asking monetary authorities to support or implement environmental policies creates a risk of capture and rent-seeking behavior, underscoring the need for transparent and careful monitoring (see chapter 8).

That said, since these subsidies are channeled through a bank that is investing in the project and takes on some of the risk—and is therefore likely to assess the project and provide additional validation—these policies provide more control and accountability than other forms of direct subsidies.

## Notes

1. A discussion of the limitations of Africa's many project preparation facilities is available from Infrastructure Consortium for Africa, http://www.icafrica.org/en/knowledge-publications/article/ica-assessment-of-project-preparation-facilities-for-africa-197/.
2. This is an illustration in one sector of the proposal made by Rozenberg et al. (2013) for the entire economy.

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# PART III

## Managing the Transition: Protecting the Poor and Avoiding the Potential Pitfalls of Reforms

# 7. Ensuring the Poor Benefit

- Climate reforms can benefit the poor and improve equity, but this requires careful attention to their design and distributional impacts.
- Fossil-fuel subsidy reform and carbon pricing generate resources that can be redistributed to compensate adverse distributional effects and to ensure that climate policies are progressive.
- Reforms of energy prices are more likely to succeed if they include a well-designed and well-communicated compensation scheme for those negatively affected.

By this point, it should be clear that decarbonizing development and securing a low-carbon future must begin with good planning. To that end, part I of this report has explored the pathways for us to achieve zero net emissions by 2100, with an emphasis on acting early with an eye on the end goal, and favoring measures that are urgent and provide synergies with economic development. But for plans to become realities, as discussed in part II, governments need to enact policies to trigger the transition and enforce those pathways. That means removing fossil-fuel subsidies, pricing carbon, adopting complementary policy packages, and securing the needed financing.

What has been left out so far is whether the resulting climate change policy packages will be socially (and politically) acceptable, which, we would argue, is a necessary condition for success. Acceptability requires those packages to be consistent with a country's social objectives, such as protecting the poor, and to garner political support. Granted, the poor are expected to benefit in the long run from mitigation policies, given that they are the most vulnerable to climate change, but it does not follow that climate policies are necessarily pro-poor in the short run. Thus, there is scope for ensuring that those policies contribute to both long-term and short-term improvements in poverty and inequality—a worthwhile goal in and of itself.

In part III, we focus on how to navigate the potential downsides and pitfalls of reform, especially on the social front. Fortunately, the evidence suggests that carbon pricing and fossil-fuel subsidy reform can easily be designed to be pro-poor—not least because those measures generate resources that can be recycled in direct cash transfers to maintain or improve poor households' welfare. As to land-use-based mitigation policies, their distributional impacts depend entirely on their design.

However, protecting the poor and most vulnerable may not be enough. As the next chapter contends, it may also be necessary to smooth the overall short-term economic cost and compensate those who stand to be most affected.

## Direct Distributional Impacts of Right Pricing—Possibly Positive?

Let's start from the question of how higher energy prices affect poor people. We know that poor households in high-income countries are hardest hit, because they allocate a larger part of their income to energy consumption and carbon-intensive goods than richer households. As a result, higher energy prices—due to carbon pricing or subsidy removal—are regressive in high-income countries.[1]

However, this is not the net effect. Wages and capital income are also affected by energy prices, so carbon taxes may be progressive overall in countries with strong redistribution policies: in such countries, poor households derive a larger fraction of their income from government transfers that are indexed to inflation (and thus largely unaffected by carbon pricing). A modeling exercise for the United States (Rausch et al. 2010) finds that this *income effect* dominates the consumption one in determining distributional outcome.

The story in developing countries could be quite different, although so far few studies are available (Ruggeri-Laderchi 2014). On the consumption side, energy price increases are likely to be progressive as modern energy's share of household budgets rises with income in developing countries, contrary to developed countries.[2] But the final impact will depend on the fuel mix used by the poor. Those who rely on traditional biomass would be unaffected by carbon price policies, although the many who use kerosene for lighting and cooking would be affected by kerosene price increases.

Households can also be affected indirectly through the price of nonenergy goods and services. Those impacts will vary, depending on the consumption baskets of poor households, their ability to substitute for other goods, and the direct and indirect sensitivity to transport costs. In principle, one would expect the urban poor—who are most dependent for their basic needs on goods transported from somewhere else and who often use public transportation for personal transport—to be particularly vulnerable to those effects. Oil prices also significantly affect food prices, especially in more remote and less urbanized regions.

On the income side, an increase in energy prices would likely be regressive in developing countries—the impact of social transfers is not as strong as in high-income countries, because many developing countries have *truncated* social safety nets that often offer less support to, or even exclude, the poorest households. And for those engaged in commercial activities, the extent of the impact critically depends on how much of the additional input cost they can pass through to final consumers. Groups that have been found to be particularly vulnerable include fishermen (who depend on diesel fuel), farmers (who use diesel pumps for irrigation), and small and medium-size enterprises. Agricultural households are also affected by rising fertilizer costs and by increased transportation costs to get their produced goods to markets.

Finally, there is a dynamic dimension to the impact of energy prices on poverty. Higher prices for modern energy could slow down poor households' transition away from biomass to modern fuels for cooking, with significant adverse health effects. And industrialization, which has been a powerful force for poverty reduction in many countries, could theoretically be slowed down by higher energy prices.

Overall, studies of the impact of *right pricing* in developing countries have focused on fossil-fuel subsidies and show that those subsidies tend to be highly inequitable and primarily benefit the rich, so that their removal will generally improve equity. The same is likely to be true for carbon pricing. But regardless of the overall impact on equity, higher energy prices may increase the depth and severity of poverty. It is critical therefore that the proceeds of the reform be used to prevent setbacks for the poorest households.

## Revenue Recycling Enables Redistribution and Allows for Pro-Poor Climate Policies

The great advantage of both fossil-fuel subsidy reform and carbon pricing is that they generate resources that can be redistributed. Almost all simulations find that when carbon revenues are *recycled* in lump-sum cash transfers to the population, the overall impact of the tax is to improve equity (Cohen, Fullerton, and Topel 2013). That result directly follows from the fact that poor households consume less energy, in absolute amount, than nonpoor households. For the same reason, modeling exercises agree that removing fossil-fuel subsidies and distributing the revenue in the form of lump-sum cash transfers would improve equity (World Bank 2013). For instance, data from developing countries suggest that taking $100 away from fossil-fuel subsidies and redistributing the money equally throughout the population would on average transfer $13 to the bottom quintile and take $23 away from the top quintile (figure 7.1).

Moreover, recycling only part of the revenues may suffice to make the overall scheme progressive. In British Columbia, the recycling of carbon revenue through tax cuts on both labor and capital, as well as through higher transfers to the population, is what has made the carbon tax progressive (Beck et al. 2014).

Reforms of fossil-fuel subsidies provide useful lessons on how the freed-up resources can help poor households adjust to the change in energy prices, through in-kind or in-cash transfers (Ruggeri Laderchi 2014). The following are examples:

*In kind.* Ghana's 2005 fossil-fuel subsidy reform increased the price of transport fuels by 50 percent but also included in-kind benefits for the poor: an expansion of primary health care and electrification in poor and rural areas, large-scale distribution of efficient lightbulbs, public transport improvements, and immediate elimination of school fees at government-run primary and secondary schools (IMF 2013; Vagliasindi 2012). Those policies and transfers were well-targeted to the poor and contributed to the reform's success (IMF 2013; Ruggeri-Laderchi 2014).

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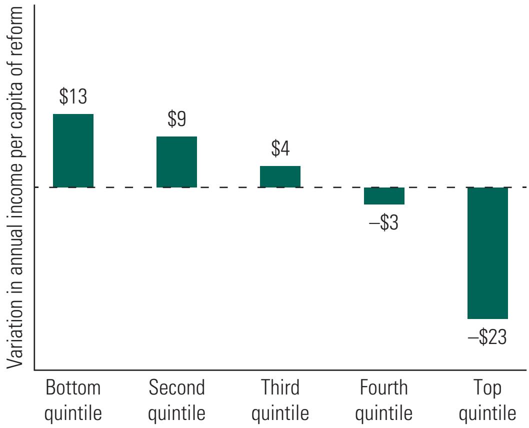
**FIGURE 7.1 Using Fossil-Fuel Subsidy Resources for Universal Cash Transfers Benefits Poor People**

*(Impact of recycling $100 from a fossil fuel subsidy to a universal cash transfer)*




*Source:* Based on Arze del Granado et al. (2012).

*In cash.* India piloted a cash transfer to replace subsidies for liquefied petroleum gas in 2014, taking advantage of the new unique biometric identifier. Indonesia has introduced programs to mitigate the effect of higher energy prices through subsidized rice, free health care, cash assistance to poor students, and a one-year conditional cash transfer targeting poor households with pregnant women or school-age children (Perdana 2014). Iran implemented a quasi-universal cash transfer (approximately $45 per month per capita) when it reformed its energy subsidies (IMF 2013). And Brazil, the Dominican Republic, Indonesia, and Mexico have used well-functioning cash-transfer programs to protect basic consumption of the poor, helping to reduce public opposition to reform (Beaton and Lontoh 2010; Diaz 2013; Vagliasindi 2012).

Other choices entail whether to expand existing social programs or to create new ones. Some fuel reforms have been used to create entirely new social programs and thus served as an impetus for social reforms, whereas others, as in India, have modernized social programs to facilitate subsidy reforms.

The ability to use new resources for those programs is what makes price-based policies so attractive—especially since some of the other instruments required in the policy package have been found to worsen inequality (box 7.1). And studies show that by alleviating the impact on the poor, policy makers sharply boost the odds of the subsidy reform succeeding. In the Middle East and North Africa, Sdralevich, Sab, and Zouhar (2014, 42) note that "of the cases where cash and in-kind transfers were introduced, 100 percent were associated with a successful outcome, while only 17 percent of the cases where these transfers were not introduced resulted in a successful reform."

Another important consideration for subsidy reform is the sequencing of reforms. One way to mitigate the poverty impact is to target existing subsidies better or to progressively phase out subsidies in a way that favors the poor. If policy makers reduce the number of goods subsidized, they should target subsidies on goods that are consumed mainly by wealthier segments of the population first (such as gasoline), before those consumed by lower-income groups (such as diesel and kerosene, which the poor use for cooking and lighting). That was the approach taken in India, Niger, and Peru. If policy makers phase out subsidies, they should initially protect the poorest individuals, possibly using a means test—which is what Brazil did with its former gas-voucher scheme.

The same is true for carbon taxes or other price instruments: sequencing changes and targeting support are key to combining poverty reduction with energy efficiency and emission reductions. For instance, a recent study finds that bringing universal access to modern cooking by 2030 requires a combination of low-cost financing for stove purchase and—at least temporarily—some subsidy for liquid fuels (in its analysis, liquefied petroleum gas) (Pachauri et al. 2013). If well targeted, such a subsidy would have a negligible impact on fossil-energy consumption and greenhouse gas

## BOX 7.1 Nonprice Instruments Are Often Regressive

**Renewable portfolio standards**

Many policies can be used to promote higher production of energy from renewable energy sources—such as a clean energy standard (CES) and a carbon price—but studies show that they do not share the same effects (Rausch and Mowers 2014). With regard to geographic distribution, the burden of a carbon price is more evenly spread across regions than the CES, which results in larger price rises in regions with low-cost coal generation than in areas with abundant clean resources. With regard to income distribution, carbon pricing may be initially regressive, but it becomes progressive if revenues are redistributed as a lump sum. In contrast, the CES is regressive and stays that way because, as a revenue-neutral system, it does not generate revenues that can be used to address concerns over distributional outcomes.

**Feed-in tariffs (FITs)**

Feed-in tariffs are designed to boost investment in renewable energy technologies by offering long-term contracts to small producers, but they also affect equity. In the United Kingdom and in Germany, FITs were found to be slightly regressive (Grösche and Schröder 2014; Grover 2013). Indeed, wealthy households tend to own more houses or land, where photovoltaic panels can be installed, and can better afford the high up-front cost of installing panels. As a result, payments for renewable electricity tend to end up in wealthy households' pockets, even as the cost of the scheme is spread over all households in proportion to their electricity consumption (and poorer households in high-income countries spend a higher share of their income on electricity). Better policy design can mitigate those drawbacks (CPUC 2013; Granqvist and Grover 2015; Macintosh and Wilkinson 2010). In California, low-income households are encouraged to participate in the scheme, and in Australia, the FIT is financed by the taxpayers (which leads to better equity as poorer household spend a lower share of their income on taxes).

emissions, and the generalization of access to modern cooking would avert between 0.6 million and 1.8 million premature deaths annually in 2030. It would also contribute to gender balance and educational opportunities, as woman and children spend a significant amount of time collecting solid fuels (WHO 2006).

## Managing Perceived Impacts

It is not just impacts that matter, but also perception of impacts. Lessons from a number of successful reformers underscore that even good reforms need to be supported by a solid understanding of the country's political economy and a well-crafted communication strategy (box 7.2). Thus, building support requires clearly articulating the goal of the reforms and managing both actual and perceived impacts (IMF 2013).

### BOX 7.2 Tips on a Good Communication Strategy for Fossil-Fuel Reform

Many countries have stumbled—and sometimes failed—in their attempts to remove fossil-fuel subsidies, but Ghana shows how a carefully crafted strategy can make a difference. Its reform package in the mid-2000s included a strong communication campaign that answered the critical "what's in it for me?" question before the public had been influenced by other sources of information (Ruggeri Laderchi 2014). The subsidy's negative impact on equity was documented and presented to the public in an easily accessible manner. And mitigation policies (health, education, and energy access) were targeted to the poor and communicated by radio broadcast. Key lessons that have emerged from this and other reform episodes include the following:

**First, understand the audience**

Understanding the audience is vital as "the success of strategic communication does not depend on creative messages or enticing incentives to try new practices. Rather, it demands a clear understanding of the perceptions, motivations, beliefs, and practices of everyone involved in or affected by a reform program" (Cabañero-Verzosa and Garcia 2009, 7). That means determining not only who is concerned and what they stand to gain and lose but also what they know about the issue, along with their preferences, beliefs, and values. The Egyptian government sponsored a survey in 2014 that found that nearly 70 percent of households did not know the scale of the energy subsidy (figure B7.2.1)—even though it absorbs 8 percent of gross domestic product and 39 percent of the government's budget. Plus, most households believed that energy prices were already too high. Similarly, in Morocco, a 2010 survey found that 70 percent of the population was unaware of the energy subsidy that absorbed 5.5 percent of gross domestic product, or 17 percent of the government budget (World Bank 2012).

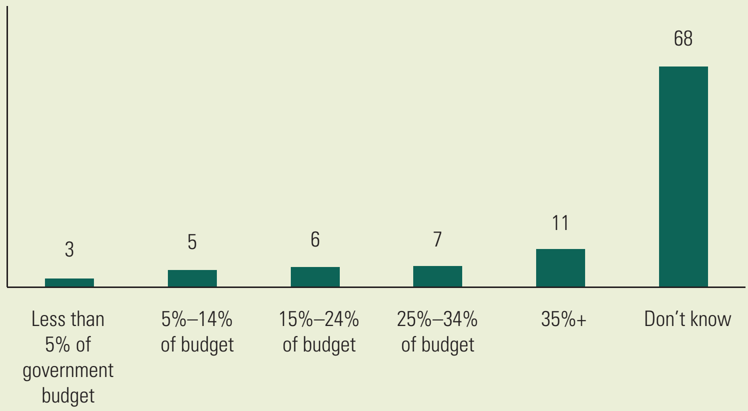
**Second, choose the message**

Keep it simple, positive, and tailored to the various audiences—always answering the "what's in it for me?" question. In Iran's 2010 fuel reform campaign, the message was that the reforms were not about eliminating subsidies, but about switching subsidies from *products* to *households*.

(*Box continues on the following page.*)

**BOX 7.2 Tips on a Good Communication Strategy for Fossil-Fuel Reform (continued)**

**FIGURE B7.2.1 Most Egyptian Households Were Unaware of the Size of the Energy Subsidy**
*(Household beliefs about the size of the subsidy)*




*Source:* Egyptian Ministry of Petroleum et al. (forthcoming).

*Note:* Bars shows shares of respondents believing that the size of the energy subsidy is a particular amount. The actual amount of the subsidy is 39 percent of the government budget (IMF 2013).

**Third, choose the channels of communication**

Channels of communication need to be tailored to the different audiences. In 2013, when Malaysia decided to tackle the $7.9 billion fuel subsidy, the government relied on a variety of channels:

- A public forum on fossil-fuel subsidies inviting members of Parliament, leading academics, business leaders, and representatives of consumer groups to address the key issues.
- A public survey asking two simple questions: Malaysia spent RM 74 billion on subsidies in 2009 causing a fiscal deficit. (1) Should subsidies be reduced? (Yes/No). (2) If Malaysia reduces its subsidies, should it be done: In one year? Over three years? Over five years?
- YouTube videos explaining basic information about fuel subsidies.
- A Twitter account for announcements and answering questions from the public on the topic.
- Engaging public figures to write about subsidy-related issues in the media.

For example, one reason for the unpopularity of carbon prices may be the perception that they impose a disproportional cost on low-income households, or particular groups, such as inhabitants of rural and remote areas and energy-intensive business (Dresner et al. 2006; Gaunt, Rye, and Allen 2007; Harrison and Peet 2012; Kallbekken and Aasen 2010; Kallbekken, Kroll, and Cherry 2011).

Communication about the distributional impact is therefore critical. In Bolivia, the public was not aware that a new cash-transfer scheme was funded by, and meant to compensate for, fossil-fuel subsidy removal. The cash transfer was well received, but the public opposed the subsidy removal, which was eventually rolled back (Ruggeri Laderchi 2014). In British Columbia, the carbon tax was not actually regressive, and it did not hit rural households disproportionally, but that was not communicated to the general public (Harrison and Peet 2012).

Furthermore, it is critical that steps to protect the poor during the transition not be limited to a one-off payment to buy off opposition in exchange for permanently increased energy prices. Fossil-fuel subsidy removal and carbon pricing provide a sustainable source of revenue for governments, thus giving them the opportunity to implement sustained policies to combat poverty.

## Land-Use-Based Mitigation—Impacts Depend on Design

As for land-use-based mitigation, its impact on equity depends on how the policies are designed (Barbier 2014). The key issues that arise are access to and returns from land and demand for labor-intensive activities. Both national and global schemes can be designed to be pro-poor, although global large-scale, land-use-based mitigation is more complex, as it affects income distribution through changes in commodity prices (box 7.3), which are not in the control of countries designing national mitigation actions.

***Access to land.*** Land-use-based mitigation policies can be designed to protect poor rural communities' access to land or even to strengthen their land titles. Often poor people depend on ecosystems for food, fuel, materials, and income generation (Angelsen et al. 2014). In particular, indigenous people's livelihoods frequently depend on non-managed lands, which store large stocks of carbon (Ricketts et al. 2010; Walker et al. 2014). Where such groups and other poor land users lack formal and secure land titles, they could be displaced by more powerful actors that seek benefits from mitigation actions (Larson et al. 2013). Yet mitigation policies can also provide an opportunity for clarifying land and resource tenure. For instance, under the Terra Legal program, Brazil has started a formal process of recognizing indigenous lands and granting land titles to about 300,000 smallholders, conditional on compliance with the Brazilian Forest Code (Duchelle et al. 2014). Also, a recent ruling by the Constitutional Court in Indonesia improved the status of forestlands used by indigenous peoples.

***Returns from land.*** One direct way to increase the incomes of poor land users is by providing payments for ecosystem services for the preservation and increase of natural carbon sinks. However, very little firm evidence exists on the distributional impacts of existing projects. Out of 1,382 studies related to payments for avoiding deforestation, only 1 (from Mozambique) undertook a formal evaluation of impacts on poor households' income. It found no significant impact (Samii et al. 2014).

Even if trade-offs are likely to occur between efficiency and equity impacts, many programs have chosen to target the poorest, thereby improving both distributional

**BOX 7.3** **Managing the Impacts of Global Land-Use Initiatives on the Poor**

Large-scale land-use-based mitigation at the global scale, especially bioenergy expansion, can reduce the availability of land for food production, with implications for food security (Smith and Bustamante 2014). Regional and local commodity prices, such as food, timber, and energy, could increase (Chen et al. 2011; Golub et al. 2013; Kuik 2013). Food price hikes could be most severe for large-scale bioenergy deployment—especially when combined with protecting natural carbon sinks (Calvin et al. 2013; Popp et al. 2011; Wise et al. 2009).

Those prices are driven by global dynamics and not by national policies, but their distributional impacts will unfold at the local level. Increased commodity prices benefit food producers but harm consumers. In the short term, food price hikes increase poverty levels, as poor people spend a larger share of their budget on food (Ivanic and Martin 2014). However, the price-induced changes in earnings from land are likely to be a more important driver of household poverty than the commodity price changes themselves (Hertel, Burke, and Lobell 2010; Ivanic and Martin 2014). Typically, landowners in developing countries are not among the poorest, meaning that relatively better-off households benefit from such policies. But even so, such price increases can also help landless poor people through higher incomes for unskilled agricultural labor (Cororaton and Timilsina 2012; Huang et al. 2012).

Further, those price impacts may be moderate. Overall, food price changes from land-use-based mitigation could be lower than those from yield decreases because of unmitigated climate change (Lotze-Campen et al. 2014). And well-planned expansion of bioenergy (e.g., using degraded areas) could reduce competition for land used for food crops.

impacts and legitimacy (Börner et al. 2010; Jindal et al. 2013; Kosoy et al. 2007; Sommerville et al. 2010). They include programs such as Brazil's Bolsa Floresta and Ecuador's Socio Bosque (see chapter 4). Similarly, the Guatemalan government offers forest incentive programs, which aim to support forestry activities by poor smallholders without land title. Overall, estimates are that if carbon-related payments were fully developed and pro-poor participation conditions secured by the year 2030, an estimated 25 million to 50 million low-income households could be benefiting from them (Milder, Scherr, and Bracer 2010).

***Demand for labor-intensive activities.*** Actions to implement land-use-based mitigation, such as climate-smart agriculture, land restoration, selective logging, and forest protection, are labor intensive and can thus provide jobs and revenues to poor rural households. Experiences from Chile, Colombia, and Moldova show that community-based land restoration and reforestation created new employment and stable income streams.

Land-use-based mitigation can be complex, and it often affects local users with low education levels. Hence, good communication and the participation of key stakeholders are essential. For example, in the Peruvian Amazon forest, some projects found it a struggle to explain REDD (reducing emissions from deforestation and forest degradation) policies in a way that local people could relate to—something that could undermine the acceptance of the scheme (Evans, Murphy, and de Jong 2014). Fortunately, increasing the awareness and understanding of land-use changes, their drivers, and local impacts can increase the acceptability of policy solutions (Osmond et al. 2010). And involving key stakeholders and local people early in the design of land-use-based mitigation policies increases the buy-in of relevant landscape actors. Countries such as Costa Rica, Ethiopia, and Indonesia have initiated workshops and consultations to facilitate understanding of the national REDD+ process and to involve indigenous people and civil (FCPF 2014).

Finally, some of the impact of land-use policies will be channeled through global markets and will mostly depend on the ambition and design of global policies (box 7.3). Individual countries will have little control over those global processes and will therefore have to rely on national or local policies to manage impacts.

## Notes

1. Available studies cover many countries, including Denmark (Wier et al. 2005), Ireland (Callan et al. 2009), the United States (Cohen, Fullerton, and Topel 2013), and British Columbia (Beck et al., 2014).
2. Using household survey data in nine developing countries in Africa and Asia, Bacon, Bhattacharya, and Kojima (2010) find that the evidence for total energy consumption is mixed: in four countries, lower quintiles spend more on energy than higher quintiles, whereas in five countries the shares are similar. But what matters is the share spent on modern energy, which rises in all countries from lower to higher quintiles.

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# 8. Smoothing the Transition to Make It Happen

- It is not enough to protect the poorest and most vulnerable. It may also be necessary to smooth the transition and compensate those who stand to be affected, even when they are not particularly vulnerable.
- Targeted support may be required if economic losses are concentrated on a sector or region, or in countries that are implementing low-carbon policies earlier than others.
- Available options to manage the transition and smooth its negative effects range from strengthening social protection schemes to carefully designing sector-specific climate policies and introducing compensation systems.

The transition toward carbon neutrality implies that some sectors, activities, or technologies will be replaced by new ones that are more efficient or based on zero-carbon energy sources. That cannot be done without some negative impacts on the owners and employees of those *carbon-entangled* firms or sectors. The question then is whether governments need to provide relief and to compensate losers when new policies are implemented. That question can certainly be debated on ethical grounds (is the government morally obligated to compensate losers?). But from a pragmatic point of view, government relief is usually needed for the social and political acceptability of reforms (Olson 1971; M. Trebilcock 2014; World Bank 2001, chap. 3).

Economic transitions always create winners and losers. And when losses are concentrated on a few well-identified and organized actors, like the coal industry, those actors may have a de facto ability to veto the reform. Governments can deal with that situation by designing policies in a way that avoids concentrating losses, or by compensating those most affected. Even when those affected have no moral claim to it, compensation may be necessary for reforms to pass. One dramatic example is the abolition of slavery in Britain in 1833, which involved a payment of £20 million (around 40 percent of the British budget at that time, and some $21 billion in present value) to former slave owners (M. Trebilcock 2014). More recently, experience with successful and unsuccessful fossil-fuel subsidy reform episodes suggests that compensation—and even buyouts—is key to making the reform feasible (Sdralevich, Sab, and Zouhar 2014).

Success also requires managing vested interests without getting captured by those interests. Indeed, a review of the three great energy transitions of modern times—the rise of steam during the first Industrial Revolution in the 18th century, electrification in the 19th century, and the advent of oil-fueled cars in the 20th century—finds that where vested interests were overly protected, transitions were delayed at a high cost (C. Trebilcock 1981). In France, during the advent of coal, pressure from domestic coalminers and charcoal producers resulted in the adoption of a tariff on coal imports and continued support to charcoal iron producers. As a result, French coal mining remained an uncompetitive industry of small producers relying on old-fashioned methods. In contrast, the energy transformation in Britain was swift, enabling a structural industrial change (Moe 2010). Similar successes and failures are possible in the transition toward carbon neutrality, with implications for development and welfare.

This chapter focuses on how to tackle political economy challenges to ensure that reforms can in fact be adopted and implemented. We have already made the case (in chapter 7) that it is essential to protect poor people for the reforms to succeed—as reforms must be consistent with broader social goals to be acceptable. Now, we turn to navigating the potential pitfalls of reforms that fall into the realm of (a) avoiding concentrated losses (that are both socially damaging and the source of powerful pushback), (b) managing the risk of competitiveness losses, and (c) reducing the risk of government failures. Measures that address those three sets of issues are crucial components of any realistic and ambitious green policy package—the kind that will be needed to reach the zero-carbon-emissions goal by 2100.

## Managing Concentrated Losses

There is no reason to think that a zero-carbon economy would be any less prosperous in the long run than a high-carbon one (if anything, it is likely to be more prosperous). But the transition will be disruptive in the short term. A carbon price will cause concentrated losses in carbon-intensive sectors, especially in the form of stranded assets—whose owners may therefore oppose the reform and in some cases have the power to veto it. For a carbon price consistent with the 2°C target, the value of coal power plants stranded worldwide between now and 2050 could reach $165 billion (Johnson et al. 2015). And climate stabilization will require keeping much of the known fossil-fuel reserves in the ground, leading to a loss of wealth for some countries and regions. Where vulnerable sectors, such as steel or coal mining, dominate the local economy, regional impacts could be severe, with social, cultural, and political implications.

What can be done to reduce the concentrated impacts from climate policies? One solution is to kick-start climate policies with regulations and incentives that apply only to *new* capital. That approach improves energy efficiency, creates low-carbon substitution options without hurting the owners of existing assets, and reduces vulnerability to the subsequent introduction of carbon prices (Rozenberg, Vogt-Schilb, and Hallegatte 2014). That approach is often used: energy-efficiency standards for buildings typically apply to only new buildings, as it would be extremely costly to require all existing ones to be retrofitted. Also, feebates or performance standards on new cars redirect investment toward cleaner vehicles, without hurting households that are stuck with a vehicle bought before the reform. As stressed in chapter 7, the challenge with these instruments is that they do not create resources that can be used to correct possible adverse side effects. They need therefore to be particularly well crafted.

Another solution is to adopt compensation schemes, using either resources from carbon pricing or the existing tax and social protection system. Overall, countries with strong social protection may be better able to support the transition of workers from declining polluting sectors to growing greener sectors. Social protection plays the role of *horizontal* compensation systems, since it protects households and individuals against economic shocks, regardless of their origin. In addition, specific targeted instruments can be used. When Japan modernized its economy in the 1960s and early 1970s, more public support went to traditional industries (such as textiles) than to modern growing sectors (such as electronics and manufacturing) (Beason and Weinstein 1996). Later, the 1978 Law for Temporary Measures for the Stabilization of Specific Depressed Industries helped smooth the decline of 14 *structurally depressed* industries—including textiles and shipbuilding. It did so by planning capacity reduction, reallocating resources within and outside the depressed industries, providing financial assistance to troubled firms, and mitigating negative impacts on labor (Krauss 1992; Peck, Levin, and Goto 1987).

The compensatory approach has also been used by the United States in the context of trade liberalization—typically through wage subsidies in the sectors that benefit from liberalization (to help them absorb workers from declining sectors) and unemployment insurance for the workers who remain trapped in losing sectors. Studies show that those measures can mitigate most of the losses at a very small aggregate cost (Porto and Lederman 2014; M. Trebilcock 2014). In the mid-1970s, U.S. Trade Adjustment Assistance was used to provide reemployment services to displaced workers and financial assistance to manufacturers and service firms hurt by import competition. A review of the program found that it helped workers affected by trade liberalization—more so than traditional unemployment insurance—although it did not cancel losses for the most vulnerable firms and workers (Richardson 1982).

Another promising option is to help those who could stand to lose become part of the transition and to benefit from it instead. For instance, some automakers have already positioned themselves as leaders in green and electric or hybrid cars, and thus as potential winners from more ambitious climate mitigation. Oil and gas companies can reinvent themselves if they develop technologies to capture and store carbon from the atmosphere. Research and development and innovation support are a way of supporting this transition, if they target potential losers to transform them into possible winners. Also, when pilot projects for green technologies are created, it is possible to locate them in the areas that are most likely to lose from climate policies, to ensure that all regions get some benefits from the reform. Innovative concentrated solar power generation or carbon capture and storage plants could for instance be located in places where coal is extracted, therefore creating green jobs and activities in those places. Well-designed policies could make traditional opponents supporters of the reforms.

## Managing the Fears of Competitiveness Loss

It is unrealistic to expect all countries to implement comparable environmental policies at the same time. Differences in sociopolitical context mean that some countries are moving first and will continue to do so. That situation creates the risk of a *carbon-haven effect*—whereby production of carbon-intensive goods, and associated carbon emissions, could relocate from countries with strict environmental regulations to laxer countries. Such relocation would both reduce the effectiveness of the environmental regulation and cause losses in economic growth, employment, and income.

Such fears of deindustrialization and job losses have played a large role in debates on a carbon tax and a cap-and-trade system. In Europe, the cement industry financed a study that—perhaps unsurprisingly—argued that 80 percent of the European cement market would be captured by importers if a carbon price of €25 per ton was introduced. Many other ex ante modeling studies have suggested that existing policies would have significant sector-scale effects in heavy industries, although they would lead to limited carbon leakage at the macro level (Branger and Quirion 2013).

But the reality is quite different, raising doubts about the existence of a significant carbon-haven effect. Indeed, ex post studies find no significant impact of existing environmental policies on firm competitiveness, even in heavy industries (Dechezleprêtre and Sato 2014; Sartor 2013). A detailed analysis of the European iron and steel industry shows that the impact of the European Union (EU) Emissions Trading System (ETS) on the competitiveness of the European industry remains limited, with an impact on marginal cost smaller than interannual exchange-rate variations (Demailly and Quirion 2008). Panel data from the United Kingdom's production census suggests that the introduction of the Climate Change Levy (an energy tax) had a significant impact on energy intensity, but no detectable effects on economic performance or plant exit (Martin, Wagner, and de Preux 2009).

The reason is that pollution abatement costs represent only a small fraction of production costs for most industries, and factors such as the availability of capital and skilled labor or proximity to markets are much more important determinants of firm location and competitiveness (Copeland 2012). In addition, many energy-intensive, trade-exposed industries are characterized by high capital intensity and high transportation costs, which limit their ability to relocate (Ederington, Levinson, and Minier 2005). As a result, environmental regulations typically make a small difference on productivity and employment, and jobs are unlikely to move across borders in significant numbers. And for environment regulations that raise significant revenues—such as carbon pricing instruments—the new resources can be used to improve other determinants of competitiveness through investments in education and workers' skills or infrastructure, or through reduction in capital and labor taxes.

Nevertheless, some uncertainty remains about the effect of carbon policies, given that the estimates to date are based on relatively modest mitigation efforts—and it is possible that future policies will become much stricter in some countries but not others. Thus, additional measures may be needed to maintain a level playing field between stricter and laxer countries.

In theory, carbon border tax adjustments—that is, import tariffs that tax the carbon content of imports at the difference between the domestic and the foreign carbon tax—are the best way to avoid the negative consequences of a partial implementation of climate policies. Unfortunately, an efficient tariff would be extremely difficult to estimate, as the carbon content of each good imported from each different county is different.[1] For that reason, proposals of border tax adjustments are frequently limited to those few goods for which the carbon content is large and easy to estimate, such as fossil fuels.

Furthermore, border tax adjustments pose equity issues, as low-income country exports tend to be more carbon intensive, and the border tax imposes costs on the exporter (Böhringer, Carbone, and Rutherford 2012). One way to mitigate this issue may be to refund revenues from the import tariff to exporter countries. Another is for the exporting countries to tax themselves for the carbon embedded in their exports (Copeland 2012). Border tax adjustment is also frequently interpreted as green protectionism by exporter countries, and it could be challenged under World Trade Organization rules (Branger and Quirion 2013; Monjon and Quirion 2011a, 2011b).

If border tax adjustments cannot be used, an alternative is to rebate carbon levies to energy-intensive, trade-exposed industries proportionally to their output. That can be achieved by granting free allowances to the relevant firms under a cap-and-trade scheme or by refunding part of the proceeds of a carbon tax. Such a scheme is equivalent in its economic impacts to imposing a carbon price and subsidizing domestic production (Fischer and Fox 2012). It thus corrects part of the problem, as it favors local, presumably cleaner, production, and it alleviates the competitive loss at the same time. That is done at a cost: the subsidy effect reduces the price of energy-intensive goods for domestic consumers, resulting in a loss of efficiency. Examples of successful output-based rebating include Sweden's nitrous oxide tax, whose revenues are refunded to the polluting firms in proportion to their output, and the carbon markets in California and New Zealand.

Finally, in countries with high fiscal pressure, the best way to improve the competitiveness of energy-intensive and trade-exposed industries may be to recycle carbon levy revenues through reduced distortive taxes (Metcalf, forthcoming). Since most such firms are also capital intensive, lower capital taxes offset higher energy prices in an efficient way.

## Managing the Risk of Government Failures

A successful transition will require government support to develop new sectors and technologies. It may also require helping and providing temporary support to sectors that are particularly negatively affected. But the use of sector-specific or technology-specific policies is not without risks. Here, we focus on three types of risk: (a) the risk of being wrong (picking and supporting the wrong technology or sector), (b) the risk of being captured (distributing resources to friends and political allies instead of promising firms), and (c) the risk of negative policy interactions.

Governments, notably in Asia, have often tried to modify the structure of their economy by using industrial policies to correct market failures, such as economies of scale, learning by doing, coordination failure, and latent comparative advantages. Whether those policies were cost-effective is still being debated, but the consensus is that at least in China, Japan, and the Republic of Korea , the desired structural transformation took place (Chang 2006; Harrison and Rodríguez-Clare 2009; Noland and Pack 2003; Pack and Saggi 2006).[2] Since climate policies also aim at changing the economic structure, we can draw lessons from the successes and failures of industrial policies (Hallegatte, Fay, and Vogt-Schilb 2013).

### The Risk of Being Wrong

One fear is that *governments may pick the wrong winner* when backing a specific technology. There is a real potential for costly failure and waste of scarce public resources, as illustrated by Norway's extensive support to Norsk Data, which went bankrupt in 1993. Output-based or horizontal approaches are thus generally considered superior to vertical policies (those that pick preferred technology), because they reduce the risk of capture and rent seeking by vested interests. However, absolute technology neutrality is difficult to use as a guiding principle, given that governments can never avoid setting some priorities (Azar and Sandén 2011; Vogt-Schilb and Hallegatte 2014). As such, the appropriate question is *how much*, not *whether*, a particular policy is technology specific.

Further, a reliance on market instruments (like a carbon price) is likely to favor established technologies, given knowledge externalities, learning by doing, economies of scale, and the *valley of death* that hampers the transition from lab to market. Such favoring may be optimal if the goal is to encourage the deployment of the cheapest technology available today. But if the goal is to develop the technology with the greatest potential, then it is *the market that may pick the wrong winner* (Acemoglu et al. 2012; Azar and Sandén 2011; del Rio Gonzalez 2008).

So what can be done to help governments manage the uncertainties of technological potential and production costs? First, countries should take advantage of the *embeddedness* of government officials in civil society and business networks (Evans 1995; Rodrik 2013). That means the private sector and the government agencies that regulate and support it need to collaborate and coordinate. However, those agencies may lack the capacity needed to plan, monitor, and evaluate such activities—especially in developing countries where technical capacities for data collection and analysis are often low.

Second, governments should not just support an industry; they should also collect information about technologies, costs, and potentials and avoid relying on information that firms can manipulate. For instance, the Chinese government used tenders to assess solar electricity production costs before it implemented a feed-in tariff, in the hope of collecting enough data to set the tariff at the right level. Governments also need to define success indicators that facilitate objective and predictable decisions on how and how long to support a firm or a technology.

Third, policies must have termination clauses to ensure that support is discontinued when a business or sector fails. Regardless of the ability of governments to *pick winners*, plenty of political economy reasons exist to explain why governments are worse than the private sector at *dropping losers* or terminating support when a project or business fails. Yet climate policies will necessarily support risky projects and are thus expected to experience a significant share of failures—unless a low-risk, low-return strategy is being followed (Rodrik 2013). Given that policies are likely to support a portfolio of projects, overall performance will depend on both the successful projects and their benefits, and on how the costs of the inevitable failures are minimized. East Asian countries addressed that problem by using export performance—an indicator that is difficult for local firms to manipulate—as a marker of success. Indeed, East Asian authorities were fairly ruthless in making continued protection in the domestic market contingent on export performance (World Bank 1993).[3]

## The Risk of Being Captured

Well-targeted policies face significant risks of capture and rent-seeking behaviors. That said, rents should not be avoided entirely, as the objective of green sectoral policies is to create the appropriate level of rent from low-carbon investment to facilitate the transition to a near-zero emissions economy. Thus, the objective is to find a balance in managing both market failures and the risks of government failures (Pegels 2014).

The risk of capture is particularly important when policies that promote investment in low-carbon sectors and technologies are implemented in the absence of correct price incentives. Ideally, targeted policies should be temporary and can be tested by the viability of the supported industry when the support is removed (the so-called Mill test).[4] For instance, the objective of feed-in tariffs is to shrink the cost of renewable energy until it becomes competitive against fossil-fuel power plants. In the absence of carbon pricing, however, a number of low-carbon industries (like carbon capture and storage) will remain nonviable and thus cannot be market tested.

How can those potential pitfalls be avoided? Suggestions include the following (Rodrik 2013):

- Predictable and transparent criteria that determine when public support should be terminated. Doing so is much easier for policies that are well targeted, since the target can more easily be translated into an indicator for success.
- Navigating the trade-offs between flexibility (the ability to act on new information regarding technology potentials, for instance) and predictability (needed to stimulate private investments). Feed-in tariffs are meant to provide some degree of assurance to producers, yet they need to be adjusted if input prices decrease significantly, which requires regulators and industries to share information and knowledge. France, Germany, Italy, and Spain successfully adjusted solar feed-in tariffs following changes in input prices between 2005 and 2012 (de La Tour, Glachant, and Ménière 2013), but adjustment required an iterative process with regular revision based on participatory approaches and consultations (World Bank 2013).
- Transparency and public accountability. Transparency and public accountability help ensure that the beneficiaries of sectoral policies are the public, rather than the firms receiving support. Resource allocations should be made public, and a regular auditing process is needed. An independent auditing agency could be created and held responsible for an annual analysis of how funds are distributed, although the effectiveness of such an agency is largely dependent on the existence of a free press and an active civil society that can react to mismanaged funds. Further, when supported firms and technologies cannot be subjected to a market test—possibly because of distorted relative prices—other success indicators need to be devised, such as reduced production costs or improved performance.

## The Risk of Negative Policy Interactions

This report argues that a climate policy package should include a mix of pricing instruments, targeted policies to support specific sectors, and compensatory measures. Such measures are vital to correct market failures (learning by doing), to cope with government limitations (incapacity to commit to future prices), and to avoid concentrating losses on a few actors. But policies often overlap, possibly resulting in unintended consequences with regard to cost and effectiveness.

One example is the complex interaction between the Emissions Trading System (ETS) for carbon to which firms in EU member countries are subject, and the domestic policies adopted by a number of EU countries to support renewable energy (feed-in tariffs or renewable production mandates). The problem is that those domestic policies cannot create additional abatement, because the ETS caps total greenhouse gas emissions. The result is less demand for—and hence a lower price of—emission allowances, which reduces the incentive to invest in low-carbon alternatives in the other sectors covered by the ETS. In the end, adding renewable energy support to an existing ETS tends to increase the cost of the ETS without changing greenhouse gas emissions in the sectors covered by the ETS in the short term (Böhringer and Rosendahl 2010; Braathen 2011).[5] Similar detrimental interactions have also been documented for fuel performance standards enacted at both the national and the state levels in the United States (Goulder and Stavins 2011).

Overlapping policies may also have unintended distributional impacts. For instance, support for renewable energy under an ETS tends to shift the burden of the abatement cost in two ways. It reduces the carbon price, thus temporarily favoring production from the dirtiest sources (Böhringer and Rosendahl 2010). It also tends to reduce wholesale electricity prices—known as the *merit order effect*—because renewable sources produce electricity without having to purchase the fuel (Würzburg, Labandeira, and Linares 2013). That effect tends to shift the burden of the reduction from electricity consumers to electricity producers.

There are two ways to reduce unwanted consequences from interactions among policies. Ideally, all climate mitigation policies should be designed and updated simultaneously, taking into account their interactions. Doing so requires coordinated intergovernmental action, starting with a mapping of existing policies relevant for climate mitigation, their precise objective (such as the market failure they are supposed to address), and the different government agencies involved in their implementation (Hood 2013). For instance, when the quantity of emissions allowed under the EU ETS was decided, it would have been best to take into account the fact that national governments would subsequently enact policies to promote renewable electricity.

But that approach is not always possible, especially with overlapping jurisdictions (such as national and subnational governments) and different sectoral scopes (as when the ministry of finance implements an economy-wide carbon price and the ministry of transportation implements a performance standard). Institutions may also lack the technical capacity to analyze in detail how policies interact with each other.

Thus, an easier and maybe more robust way is to favor price over quantity instruments—such as carbon taxes instead of carbon markets, and feebate schemes instead of performance standards on new capital. Indeed, overlapping price instruments interact more efficiently and more predictably (Goulder and Schein 2013; Hood 2013; Williams 2012). Under an economy-wide carbon tax, a feed-in tariff promotes investment in renewable power without reducing incentives to abate in other sectors, and under a national feebate program, more ambitious state-level feebate programs simply add up.

## Notes

1. Moreover, the optimal tariff taxes only the emissions that have not been taxed in the exporter country, which requires a precise understanding of the marginal abatement cost in both the domestic and the exporter countries (which comes not only from the carbon price but also from its interaction with other taxes and regulations and depends on both direct and indirect greenhouse gas emissions).
2. Some believe industrial policies played a key role in the catching up of Japan and other Asian countries (Chang 2006). Others believe that success was a consequence of large investments (and the associated catch-up in capital intensity) in countries that already had high education levels and institutional capacity (Krugman 1994).
3. Note, however, that subsidies conditional to export are formally prohibited by World Trade Organization rules (Charnovitz 2014).
4. Classical assessments of industrial policies often rely on the Mill and Bastable tests (Harrison and Rodríguez-Clare 2009). The Mill test asks whether the supported sector or technology can become competitive in the absence of support, whereas the Bastable test asks whether the benefit of support exceeds the cost.
5. However, support for renewable power can also complement an ETS efficiently when the price of carbon in the ETS is too volatile (Lecuyer and Quirion 2013). External factors (such as an economic slowdown or higher fossil-fuel prices) can momentarily undermine the carbon price to the point where the ETS does not provide any significant incentive to invest in low-carbon activities. In that case, support for renewable power is useful and economically efficient, in that it ensures that a minimal amount of decarbonization effort is maintained when the carbon price is too low.

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